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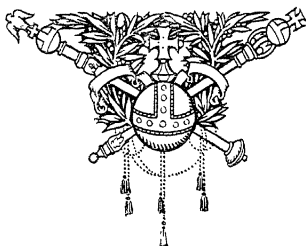   F.R.G.S., Author of *The Andes and the Amazon*, etc.

OIL FUEL

by

PROF. VIVIAN. B. LEWES,

F.I.C., F.C.S.

OIL FUEL

PREFACE

THE question of oil fuel is attracting so
much attention at the present time, and
oil is bulking so largely as a medium for
speculation, that the time seems ripe for a
book which will deal with the whole subject
from a purely impartial point of view and
present it in a form sufficiently free from
technicalities to make it of use to the lay
mind.

The student who desires to master the
subject has been amply provided for in Sir
Boverton Redwood's masterly monograph
on *Petroleum and Its Products*; the oil
producer has Mr A. Beeby Thompson's
excellent work on *Oil Mining*, while the
prospector is catered for in Mr Cunningham
Craig's *Oil Finding*; but the would-be
investor in oil shares who desires some know-
ledge of the most promising oil regions, the
shareholder who wants to understand the
meaning of the reports from the oil field,
the intending user of oil power who wishes
to grasp the points for and against its

adoption, and the multitude of others who
would like a review of the subject from the
formation of oil in Nature to its consumption
in the service of man, will find that the
desired information is so widely spread through
current literature, and is so overlaid with
detail, as to be practically unavailable to
the busy man. It is for such that the present
manual is intended : it aims at something
more than presenting a condensed review of
the subject to its readers, and some of the
views expressed, especially with regard to
the supply of petroleum, will not be accept-
able to many interested in its exploitation. ·

Scientific terms have been used as little
as possible, unnecessary detail has been
omitted, and it is hoped that the treatment
of the subject will appeal to a wide circle
of readers.

VIVIAN B. LEWES.

GREENWICH, *July* 1, 1913.

CONTENTS

CHAPTER I

THE FORMATION AND COMPOSITION OF PETROLEUM

CHAPTER II

THE OIL FIELDS OF THE WORLD

CONTENTS

CHAPTER III

THE RECOVERY AND REFINING OF PETROLEUM

CHAPTER IV

THE TRANSPORTATION AND STORAGE OF OIL

CHAPTER V

LIQUID FUELS OTHER THAN PETROLEUM

CHAPTER VI

LIQUID FUEL AND ITS COMBUSTION

CHAPTER VII

CHAPTER VIII

CHAPTER IX

THE FUTURE OF PETROLEUM AND OIL FUEL

APPENDIX I

APPENDIX II

Oil Fuel

CHAPTER I

THE FORMATION AND COMPOSITION OF PETROLEUM

Fuel—Fire—The nature of combustion—Source of the heat evolved—The Carboniferous and Tertiary periods of the earth's formation—How the atmosphere was formed—The formation of coal from terrestrial vegetation and oil from marine growths—The inorganic theories of oil formation—Theories of the organic source of oil—Other views on the formation of oil—Proofs of the marine origin of oil—Researches on seaweeds—The conditions under which solid and liquid products are formed from vegetable growths—The formation of oil strata—Anticlines—Synclines—The oil reservoir—Natural gas and gas pressure—How gushing and flowing wells are formed—The theories of oil pressure—The composition of petroleum—Hydrocarbons—The hydrocarbons present in petroleum.

THE term 'Fuel' is applied to those substances which are of sufficiently wide distribution and abundance to be generally used for the development of heat by their combustion, and they may consist either of solids, like coal and wood, of liquids, like oils and tar, or of combustible gases, such as constitute natural, coal, and producer gas.

OIL FUEL

Long ages before the Christian era fire-worship was the religion which appealed most to the primitive man on account of heat being essential to his comfort and life. He obtained combustion by raising soft wood to its ignition point by means of friction, and the fire once started was kept burning in a local temple, from which the neighbourhood obtained burning embers for lighting the domestic fires.

The fact, therefore, that the combustion of a vegetable substance like wood will generate heat was one of the earliest known truths, and when men's ideas became clearer and the desire arose to know the reason of the various phenomena of fire and flame, these attracted a large share of attention, and probably the first general scientific theory was an attempt to explain the phenomena of combustion, which was made by Stahl at the end of the seventeenth century, and which held its own for nearly 100 years.

Born in 1743, at a period when Chemistry as a science was in a very crude and unformed condition, Antoine Laurent Lavoisier devoted his life to the study of the phenomena of combustion, and formulated the first true

explanation of the cause and nature of fire.

The experiments which Lavoisier conducted proved that when a substance was burned in air the resulting products of combustion weighed more than the original body, and with this fact as a basis he discovered that air is essential for combustion. This was utterly opposed to the phlogistic theory advanced by Stahl, which had been accepted as the correct explanation of the processes of combustion in the earlier years of the century, and by which combustion was attributed to the escape of a spirit or ether, called 'phlogiston,' the presence of which rendered the material combustible. Soon afterwards the labours of Priestley, Lavoisier, and Cavendish resulted in the discovery of the composition of air, and proved that air was a mixture of oxygen and nitrogen, thus upsetting the old idea that it was an element. After the discovery of oxygen by Priestley in 1774, Lavoisier was enabled to complete his work on combustion, and as the result of noticing the impetus given to all processes of combustion by this element, he came to the conclusion that combustion was the manifestation of

energy during the rapid chemical combina-
tion of the combustible body and the oxygen
of the air. In all the ordinary forms of
combustion energy is developed by chemical
combination, and owing to its intensity by
concentration into a short space of time this
energy manifests itself as heat and gives
the incandescence, flame, and light which
we look upon as the chief phenomena of
combustion.

Carbon—one of the most widely distri-
buted of that class of bodies which we call
elements, because we are unable to decompose
them into anything more simple than them-
selves—forms the basis of all fuels, and occurs
in the forms which are mostly used for the
generation of energy combined with hydrogen
and other elements.

Both coal and oil owe their origin to those
marvellous actions which, during the forma-
tion of the world, rendered latent the energy
of the sun's rays and stored it for the use of
man, and in doing so rendered life a possi-
bility by the formation of an atmosphere
in which men and animals could exist.

In its earliest inception the world was
a nebulous mass of incandescent matter
surrounded by an atmosphere of products of

combustion which so diluted the oxygen and nitrogen that, even if they were present in the same ratio as we find them to-day, they formed but a small percentage of the whole. As the earth cooled from the radiation of heat into space, a thin crust slowly formed around the molten mass, and when the outer surface of this crust had sufficiently cooled, low forms of vegetation made their appearance, and grew with a superabundant luxuriance that can never again be equalled.

The products of completed combustion are carbon dioxide and water vapour, the compounds formed by the combination of oxygen gas with carbon and hydrogen respectively, and in the growth of plants, both terrestrial and aquatic, carbon dioxide and water are absorbed. Under the influence of the sun's rays a wonderful series of chemical actions is then set up in the plant cells, which finally results in the fixation of the carbon and water as the class of compounds we know as 'celluloses,' whilst the oxygen originally present in the carbon dioxide is set free.

During the long ages that elapsed between the appearance of vegetation and the coming of man, this action gradually reduced the

atmospheric carbon dioxide to a minimum, and
in its place put the oxygen which is essential
to animal life; whilst life, together alter-
nating with the processes of decay, absorbs
the oxygen and replaces it by carbon dioxide,
and from the commencement of life on the
earth to the present day these wonderful
cycles have balanced each other and helped
to keep the atmosphere of the world constant.

During the Carboniferous and Tertiary
periods of the world's history our coal and
lignite deposits were formed from the
monster vegetation, which, under the con-
ditions of high temperature from the cooling
earth and abundant carbon dioxide and
water vapour in the forming atmosphere,
grew with rapidity and luxuriance, and,
checked in its decay by the paucity of atmo-
spheric oxygen and finally covered and
protected by overlying strata, became in long
ages converted by heat and pressure into
our chief solid fuel.

During these same periods much of the
world's surface was covered by shallow seas,
and the same factors which forced the earth's
vegetation to abnormal proportions also
caused the growth of equally prolific marine
vegetation and low forms of life, the decay

of which was not only checked by the shortage of dissolved oxygen in the water, but also by the pickling and preservative action of the brine concentrated by rapid evaporation of the sea.

Under these conditions the slowly rotting marine growths, both animal and vegetable, were deposited with the sedimentary sand and calcareous matter of minute marine organisms, and gradually, as the ages passed, this mass became sealed in by further impervious deposits, and strata after strata piled themselves above.

· Heated from below and subjected to pressure from above, the organic matter through unknown periods of time stewed in its brine bath, and gradually underwent decompositions that have resulted in the formation of petroleum and natural gas, which as they were formed took the place of the organic matter in the sand and in the cavities of the limestone formed from the minute shell deposits, which in this way acted as a porous reservoir for them, and which, where the sealing upper strata remained unbroken, has retained them to the present day, thus giving the world its oil fields.

Many other theories have been advanced

to account for the natural production of
petroleum, and these may be divided into
two classes, the first being that it is of
inorganic origin, and the second that it has
an organic source.

Several brilliant scientists, amongst whom
were Berthelot, Mendeléeff, and Moissan,
considered that petroleum is formed in
the interior of the earth by the action of
steam upon the compounds of metals with
carbon, a class of bodies that we call carbides,
and that in the same way that water causes
the liberation of the hydrocarbon acetylene
when it acts on calcium carbide, so does
the steam liberate hydrocarbons from other
carbides at subterranean depths and high
temperatures, and these, escaping towards
the surface, become condensed as petroleum in
the absorbent strata in which they are found.

The fact which supports this inorganic
origin of petroleum most strongly is that the
carbides of some of the rare metals, such as
lanthanum, uranium, and cerium, actually
do yield petroleum-like bodies when acted
upon by water; but the theory is not accepted
by any who have practical knowledge of
the oil fields, from the fact that the alterna-
tion of equally porous beds free from and

saturated with petroleum shows that it has been generated in the strata in which it is found, and has not penetrated to them from exterior sources.

The supporters of the organic theory of formation are split up into two factions—the one considering the oil to be of animal origin, the other that it is derived from vegetable matter. This variation in their views on the subject is due to the fact that undoubtedly some oil fields were formed from deposits in which low forms of animal matter were plentiful and gave their characteristics to the oil, whilst in the other cases the vegetable constituents predominated.

We know that most of the chalk and limestone formations have been produced by the deposition of infinite myriads of minute forms of marine life, the shells of which are composed of calcium carbonate, of which both chalk and limestone consist, and it is clear that if these minute shells still contained in a but slightly decomposed condition the original low forms of life that created them, and that there were enormous masses of vegetable sea growths scattered through the depositing mass as well, there is ample material to form the volume of petroleum

we find in the strata. It must also be remem-
bered that some of the porous strata-bearing
petroleum are limestone and will contain
an 'excess of the animal product, whilst the
other petroleum strata are sandstone, and
the oil will be of more vegetable origin; and
in this way quite likely produce the differ-
ences which are found in the oils from various
fields.

Remembering the wide variations which
exist between the coals formed in the Carboni-
ferous period and the lignites of the Tertiary
formation, we should expect differences in
the liquid hydrocarbons due to differences in
the form of animal and vegetable life from
which they sprang, and it must be borne in
mind that small oil deposits, such as are
found in conjunction with coal and lignite
fields, and even sometimes in peat, are not
due to such actions, but to the distillation
of these carboniferous materials by the intru-
sion of igneous matter.

Some observers condemn the idea of marine
vegetation having played any part in its
production, and contend that, although in
stagnant marine areas seaweeds grow with
luxuriant abundance, in deep ocean waters
weed is practically absent, and the quantity

of weed needed to yield the petroleum deposits makes such origin impossible, whilst a still more insurmountable objection to such a theory is that 'when the water ·is removed from seaweed, of the remaining solids·a considerable proportion is bromine and iodine in the form of salts,' and ask, 'If petroleum is formed from the remains of seaweed, what becomes of these bromides and iodides which must be present in enormous quantity?' They also point out that every sample of petroleum contains some sulphur, and that seaweed contains none, and conclude that for a theory of marine origin 'the chemical difficulties to be surmounted are therefore as insurmountable as the initial difficulty of accumulation in sufficient quantity.'

These objections seem to be based on the fallacy that the kind and conditions of growth of marine vegetation were the same in the Carboniferous and Tertiary periods as they are to-day. It is certain that in those ages, when the cooled crust of the earth was extremely thin, 'stagnant marine areas,' shallow in depth, were the only ones possible, and that rapid evaporation, condensation, and excessive rainfall were the

prevailing conditions, the warmth and satura-
tion of the water with carbon dioxide making
the marine growths as luxurious as the ter-
restrial growths, and probably of the same
low order, whilst the terrestrial rainfall
washed into the shallow lakes and seas the
sand and silt that covered the weed and
formed the permeable strata in which we
find the oil in many districts, whilst in others
the depositing calcareous remains of low
forms of marine life performed the same
function.

   Turning to the chemical objections to the
theory, we find them of much the same
character. The salts in solution in sea water
are the result of concentration over geological
ages, the most soluble, like chlorides, bromides,
and iodides, increasing in quantity, whilst
the less soluble, like sulphate and carbonate
of calcium, when they reach the point of
saturation, deposit as solids. Throughout
the ages during which this has been going on
in the ocean the sodium chloride has risen
to 1850 grains per gallon, whilst the iodides
and bromides, which are quite as soluble,
are still minute traces only distinguishable
after much concentration, so that it is prob-
able that even at much later periods than those

of the Carboniferous and Tertiary eras no
iodine or bromine was present in the water,
whilst even if they were, it is only certain
classes of marine weed which absorb them
in more than mere traces, and it is
quite possible that none of the lower
forms of growth existing at those early
periods did so.

Probably the seaweed richest in iodine is
'Tangle-wrack' (*Laminaria digitata*), the
soluble ash of which contains less than a half
per cent. of iodine, whilst the commonest
weed, the 'Bladder-wrack' (*Fucus vesicu-
losus*), contains less than 0·01 per cent., so
that the 'considerable proportion' and 'enor-
mous quantities' spoken of by opponents to
the theory are not so formidable after
all.

The sulphur in oil is fully accounted
for by sulphates, always present in the ash
of the weed and also probably depositing
from the sea water, becoming reduced to
sulphide by the vegetable remains, and
yielding mercaptans, thiophenes, and
sulphides as the hydrocarbons form from the
celluloses of the marine growths. It is
perfectly well known that on the sub-tropical
coasts, where rivers bring down vegetable

matter into the sea, sulphides are formed in
such quantity by the reduction of sulphates
in. the sea water as to blacken white lead
paints when used on a ship.

Kelp, the ash left after burning seaweed,
contains so much sulphur as sulphides that
it often gives off sulphuretted hydrogen
when moistened with water, and consider-
able quantities of this gas are always evolved
when the kelp is treated with acid.

Setting aside the change from prehistoric
conditions, let us see how the evidence that
can be obtained from marine growths of
the present age favours the theory of
their being possibly the original source of
petroleum.

In the early sixties of the last century the
utilisation of seaweed for the recovery of
iodine attracted a good deal of attention,
improvements upon the old kelp burning
being under consideration, and researches
made at that time by Mr E. C. C. Stanford
with this object in view throw considerable
light upon the oil-yielding properties of
seaweed when submitted to destructive dis-
tillation at a low red heat.

He found that under these conditions all
kinds of seaweed yielded an inflammable

gas consisting of mixtures of oxides of carbon
and hydrocarbons, water containing ammonia
salts on which, after condensation, floated
a layer of naphtha, and a fluid tar containing
oil in considerable quantities, which could
be separated into a volatile portion having
the appearance and properties of a mixture
of pure hydrocarbons analogous to those
from coal tar naphtha. Distillation at a
higher temperature yielded a ' fixed oil '
containing on the average about 5·2 per
cent. of a crude acid analogous to creosote,
and after purification with potash and sul-
phuric acid this oil resembled 'the paraffin
oil of commerce.'

The process he recommended for the treat-
ment of the tar was as follows:—The tar is
siphoned off and distilled with an equal measure
of water in an iron tar still: the light volatile
oil passes over with the condensed water, on
which it floats. This is decanted, and treated
with dilute sulphuric acid, which removes
picoline and other oily bases, and the red
colouring matter is deposited. This substance
is washed and dissolved in spirit, and the
solution deposits it on evaporation. The
light oil is then agitated with from 5 to 10
per cent. of oil of vitriol, washed with water

and caustic soda, and finally redistilled.
The residual tar, from which the light oil
has been removed, is then pumped into another
iron still, and a greater heat applied.   The
paraffin oil is thus obtained, and purified by
oil of vitriol, caustic soda, and redistillation.
The residual pitch may be employed for the
manufacture of patent fuel, etc., or pumped
while hot into brick ovens provided with an
iron pipe to carry off the heavy vapours,
and subjected to a red heat, by which a
further portion of paraffin oil is obtained, and
a good coke left in the still.

By the destructive distillation of a ton of
each of the following species of weed he
obtained—

SPECIES.	PRODUCTS.			
	Vola- tile oil, oz.	Paraf- fin oil, oz.	Naph- tha, oz.	Gas, cubic feet
Laminaria Digitata .	253·4	250·2	161·3	1205
Laminaria Saccharina .	253·7	285·3	153	956
Fucus Vesiculosus . .	354·5	515·4	220·8	1052
Fucus Serratus . .	295·7	332·6	112·9	1089
Fucus Nodosus . .	—	418·6	—	1504
Zostera Marina . .	118·8	108·2	127·2	1234
Rhodomela Pinas- troides . . .	114·3	144·8	172	500

i.e. from the commonest weed it is possible
to obtain 6·7 gallons of oil per ton.

An interesting point is that the genus
Fucus, which yield the largest volume of
paraffin oil, is the genus which contains
the least iodine and the largest proportion
of sulphates.

It must be borne in mind that in these
experiments a temperature of something
like 500 to 800° C. was employed, and as
the result, compounds were produced having
the characteristics of some of those derived
from coal, and we know that in the destructive
distillation of coal the lower the temperature
employed the more paraffinoid in its character
the tar becomes, so that when distilled at the
lowest possible temperature benzene and
other aromatic hydrocarbons are absent,
or present only in very small quantities,
whilst paraffins and naphthenes are present
to a large extent. This strongly supports
the idea that petroleum is derived from
vegetable matter, whether it be terrestrial
or marine, and I think the facts which have
been deduced point fairly conclusively to
the marine origin being the more likely
one.

Peat, when heated under pressure in the

presence of water, yields bodies of the character of petroleum, and the fact that paraffin wax can be extracted from peat in various processes is well known, so that it becomes more or less a question of probability as to whether peat or seaweed is the source of the petroleum found in nature.

Experiments show that when peat is treated under exactly the same conditions as in Stanford's researches, the volume of paraffin oil formed is less than one-half of that yielded be seaweed, which is a point in favour of the marine theory.

In the conversion of vegetable matter into fuel, whether it be coal or oil, the actions which take place consist of concentration of the carbon and hydrogen in the organic molecule and elimination of the oxygen, whilst the formation of the simplest gaseous hydrocarbon, methane, yields the fire-damp in the coal measures and the natural gas in the oil strata; but whilst in the case of the coal formation there is always a large excess of free carbon and incomplete elimination of oxygen, in the production of oil the action has been of a different character, the concentration of the hydrogen being greater than that of the carbon, and the oxygen

probably entirely eliminated as carbon dioxide.

It is absurd to attempt to express great natural changes by equations, but my meaning might be illustrated as follows :—

Suppose the celluloses present in vegetation, terrestrial and marine, to be represented by the general formula $C_6H_{10}O_5$, it would be quite possible under certain conditions to have the decomposition proceeding as in the case of checked decay in the formation of the free carbon in coal—

$$2\ C_6H_{10}O_5 = \underset{\text{Carbon.}}{6\ C} + \underset{\text{Methane.}}{3\ CH_4} + \underset{\substack{\text{Carbon}\\\text{Dioxide.}}}{3\ CO_2} + \underset{\text{Water.}}{4\ H_2O}$$
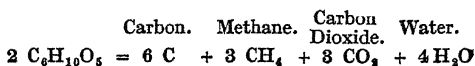
an equation which has been used to express the formation of coal. Under other conditions the changes might be—

$$4\ C_6H_{10}O_5 = \underset{\substack{\text{Carbon}\\\text{Dioxide.}}}{10\ CO_2} + \underset{\text{Methane.}}{5\ CH_4} + \underset{\text{Nonane.}}{C_9H_{20}}$$
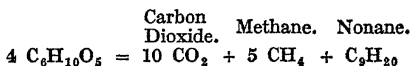
which would represent the formation of natural gas and one of the most important fractions of petroleum, whilst the carbon dioxide dissolved in the brine under enormous pressure would slowly become absorbed in actions upon the mineral matter present,

such as forming carbonates and soluble bicarbonates of magnesia, thus dolomiting the calcareous deposits.

The question then arises as to why one form of vegetable growth should be converted into solids like coal and lignite, whilst another of practically the same chemical composition should yield liquids like petroleum.

It seems likely that this is due in part to the difference in structure of the vegetable material, all that of terrestrial origin being fibrous, whilst in the case of marine growths of the present day it is only the sea grass, which is not a true seaweed, that shows any sign of fibre ; and when we consider the resistance to change that fibres possess, it may well be that these have formed a frame or nucleus which has helped to determine the formation of hydrocarbons in a solid rather than in a liquid condition. Any one who has examined many samples of lignite, the tertiary coal, knows that in some cases the fibrous structure of the original wood is distinctly visible, and the small amount of change that has taken place in the lignose of the fibre in all probability accounts for the high oxygen content of this class of coal.

It must be borne in mind, also, that in the formation of coal or lignite there has been an enormous mass of drift or of peat with very little admixture with sand or other mineral matter, compressed by the often impermeable strata that have formed above it, whilst the dense masses of seaweed growing below water have been mixed with and sub-divided by the sedimentary matter, and we know that alterations in the character of the decompositions taking place are often induced by such variations in condition.

Another point that must not be lost sight of is that no high degree of temperature is needed to explain the changes that have taken place, and that although in the laboratory we have to heat wood or peat to nearly 400° C. before any true distillation takes place, changes such as have produced petroleum will take place, well below the boiling-point of water if continued under pressure for geological ages, and the whole character of the petroleum constituents shows them to have been formed at moderate temperatures.

During the formation of the earth, volcanic movements or contractions during cooling caused a fluting of what would

otherwise have been horizontal strata, and
where the stratum of sand or limestone that
is acting as a reservoir to the oil has been
contained between other impermeable strata,
this puckering or creasing has given a curve
to the formation, which in some cases shows
itself as hills or in extreme cases mountains.
In the latter case the disturbance has often
been so great as to break the containing
crust, and liquid hydrocarbons are rarely
found; but where the deformation has been
of a more gentle character and broad low
curves have been produced, the upper portion
or arch forms what is known as an 'Anti-
cline,' and the dip or trough is known as
a 'Syncline.'

Water holding much salt in solution, known
as brine, is an almost universal accompani-
ment of oil; and as it is heavier than the oil,
the latter rises in the sand to the upper part
of the anticline, whilst the brine remains in
the syncline, and if any large volume of
natural gas is evolved it collects in the
extreme top of the arch of the anticline, and
often creates a high pressure on the surface
of the oil and water, so that if a boring is
made into the side of the anticline where
the porous deposit is filled with liquid,

the gas pressure drives the oil up the boring.

In some cases the earth movement which caused the throwing up of the anticline has acted at two points far apart, forming a long low crowned anticline, which is often called a 'terrace,' and where this formation occurs gas and oil are often found over a considerable area.

To those unacquainted with the oil formations it often seems incredible that the volume of oil discharged from a single well can have come from a reservoir of such material as sandstone or limestone; but the ordinary sands—sandstones and limestones—under pressure can absorb and retain from 10 to 50 per cent. of water, so that under the enormous pressures existing in many anticlines where the oil-bearing stratum is of considerable thickness, the volume of oil obtained is accounted for, one well under high pressure discharging the oil from a very large area of an oil-producing stratum.

In oil-getting, the great value of the anticline is that it forms an accumulating centre for the oil, so that an amount of oil which, if spread over a flat formation, would be impossible to work profitably can, when floated

into the anticline by gravity above the brine, be successfully obtained. There are, however, many oil-fields in which such structure is absent.

In the same way that opinions have differed as to the source of the petroleum, so various views as to the causes of the pressure that in many cases drives the oil up the shaft of the well from great depths have been put forward.

Oil is confined to sedimentary strata and has been stored *in situ,* and wherever the capping stratum has remained unbroken is found accompanied by gas, and under pressures which vary between very wide limits— as high as 1000 lb. per square inch being recorded, whilst 600 to 800 lb. were not unusual in Pennsylvania.

The result of this is that, when the containing stratum is pierced in boring, so fierce a rush of gas, oil, sand, and sometimes brine takes place that the tools and occasionally the casings are driven out of the bore and much damage ensues, enormous volumes of oil being lost before the flow can be got under control.

In Sir Boverton Redwood's work on *Petroleum,* he quotes the following description

of the tapping of one of the Bibi-Eibat gushers :—'From the town the fountain had the appearance of a colossal pillar of smoke, from the crest of which clouds of oil sand detached themselves and floated away a great distance without touching the ground. Owing to the prevalence of southerly winds, the oil was blowing in the direction of Bailoff Point, covering hill and dale with sand and oil, and drenching the houses of Bailoff, a mile and a half away. . . . The whole district of Bibi-Eibat was covered with oil, which filled up the cavities, formed a lake, and on the fifth day began flowing into the sea; the outflow during three days was estimated at 5000 or 6000 tons daily. . . . On the eighth day the maximum was reached, the oil then spouting at the rate of 11,000 tons, or 2,750,000 gallons a day. After the tenth day it began to diminish, and by the fifteenth day the engineers had so far got it under control that the outflow was only 250,000 gallons a day. Altogether over 10,000,000 gallons of oil came to the surface, and most of this was lost for want of storage accommodation.'

The early view of the cause of these great pressures was that they were caused by the weight of the earth above the oil stratum; but

this idea is manifestly absurd, as many of the
absorbent limestones that hold the oil, after
the oil has been withdrawn, would carry ten
times the pressure of the overlying strata
without being crushed or compressed, whilst
if this were the cause, the pressure would
remain constant until the oil stratum was
squeezed dry—which it does not.

The second theory, which was much more
widely adopted, was that water found its
way into the stratum at some distant out-
crop, and so gave a head of water that created
the pressure. This view, although it might
conceivably be possible in some cases, is
quite inadequate to explain many of the
pressures found, and if it were true, every
flowing well that ceased to give oil should
gush water, which again is not the case.
All one's experience points to the fact
that it is gas collected and compressed by
having to find space for itself in the arch of
the anticline that gives the pressure.

Crude petroleum as it comes from the well
is a dark brown, sometimes almost black,
liquid, although in some parts of the world
small deposits of what are called 'white oil'
are occasionally found, these consisting of
petroleum which has been decolourised by

passage through soil of the character of fuller's earth.

The oil, whatever its colour, is a mixture of many compounds of hydrogen and carbon, which' are known by the generic name of 'hydrocarbons.'

The element carbon occurs free in nature in several so-called allotropic modifications, and is found in the perfectly pure state as the diamond, whilst it is also practically pure in the form of graphite or black lead, the one the hardest substance known, whilst the other is so soft that it is used for the cores of pencils, rubbing off on the surface of the paper and yielding a black mark.

Most elements on entering into combination with others do so only in a very few definite proportions; but carbon has the property of forming some hundreds of different bodies in combination with hydrogen, and these so-called hydrocarbons exist in such numbers that to obtain something like order in their classification they are arranged in series, the members of which bear the same ratio between the number of carbon and hydrogen atoms present in the molecule.

The most important series is that known as the saturated hydrocarbon, or paraffin, series,

all the members of which contain carbon and
hydrogen in the ratio of C_nH_{2n+2}, n being
the number of atoms of carbon; and it is
this series which plays the most important
part in petroleum from the American fields.
The simplest member of the series is
methane, represented by the formula CH_4;
this compound is gaseous, and is found
as the chief constituent of the natural gas
occurring in all oil wells, as shown in the
following table :—

NATURAL GAS

	Russian Baku.	American Ohio.	English Heathfield.
Hydrogen .	0·98	1·89	0·00
Methane . .	93·09	92·84	93·16
Ethane . .	3·26	0·35	2·94
Carbon dioxide	2·18	0·75	0·00
Nitrogen .	0·49	3·82	2·90
Oxygen . .	0·00	0·35	0·00
Carbon mon- oxide . .	0·00	0·00	1·00

The members of this series which have
been isolated from American petroleum are
as follows :—

	Boiling Point °C.	For- mula.	Specific Gravity.	Con- dition.
Methane .	..	CH_4	..	Gaseous
Ethane .	..	C_2H_6	..	,,
Propane .	..	C_3H_8	..	,,
Butane .	6	C_4H_{10}	..	,,

	Boiling Point °C.	Formula.	Specific Gravity.	Condition.
Pentane (normal)	38	C_5H_{12}	0·628	Liquid.
Hexane .	69	C_6H_{14}	0·664	,,
Heptane .	97·5	C_7H_{16}	0·699	,,
Octane .	125	C_8H_{18}	0·703	,,
Nonane .	136	C_9H_{20}	0·741	,,
Decane .	158	$C_{10}H_{22}$	0·757	,,
Endecane .	182	$C_{11}H_{24}$	0·765	,,
Dodecane .	198	$C_{12}H_{26}$	0·776	,,
Tridecane .	216	$C_{13}H_{28}$	0·792	,,
Tetradecane .	238	$C_{14}H_{30}$	..	,,
Pentadecane .	258	$C_{15}H_{32}$	..	,,
Hexadecane .	280	$C_{16}H_{34}$	..	,,
Octodecane .	..	$C_{18}H_{38}$	..	..
? . .	..	$C_{20}H_{42}$	..	..
? . .	..	$C_{23}H_{48}$	..	..
? . .	..	$C_{25}H_{52}$	..	..
Paraffin (myricil)	..	$C_{27}H_{56}$	..	Solid.
,, (ceryl)	370	$C_{30}H_{62}$	..	..

In the Russian oils the more important members belong to the series of hydrocarbons known as naphthenes or hexahydrides, in which the ratio of carbon to hydrogen is $\frac{2n}{}$

The general properties of the oil, however, from whatever source obtained, are so closely akin that for ordinary purposes the composition of the various crude oils may be looked upon as practically the same as the American oils.

Crude petroleum, as obtained from the well, has a specific gravity which will vary

between the limits of 0·77 and 1, as compared with water, although neither of these extremes is often met with, the bulk of the crude oil falling between the limits of 0·844 and 0·899. Where the heavier oil is found it generally means that it has been collected from shallow depths, and has increased in specific gravity by losing some of its more volatile constituents by evaporation. Some oils, however, which contain a high percentage of solid hydrocarbons dissolved in them may also have a high specific gravity.

With these hydrocarbons it is generally found that the more simple members of the series are gaseous, and that as a larger and larger number of atoms are condensed into the molecule the compound becomes liquid, whilst the highest members as a rule are solid.

This is well exemplified in the paraffin group from Pennsylvanian petroleum, in which the first four members, methane, ethane, propane, and butane, are gaseous, whilst the fifth and following members are liquids, becoming less and less volatile as they pass from pentane, C_5H_{12}, up to about the fifteenth member of the group, when they get of a pasty consistency, and a mixture

of the fifteenth and sixteenth members forms
the substance generally known as vaseline.
The compounds get more and more solid
the higher they ascend in the series, until at
about the twenty-seventh member one arrives
at solid paraffin.

After it has been obtained from the well,
this mixture of many compounds has to be
refined and fractionally distilled, in order to
separate from it the most marketable
products.

CHAPTER II

THE OIL FIELDS OF THE WORLD

The wide distribution of oil—The introduction of mineral
    oil for lighting—The discovery of mineral oil in
    America and Russia—The early days of oil produc-
    tion—The world's output of petroleum—The oil-
    fields of America—The Russian fields and the direc-
    tions in which they will expand as the present fields
    become exhausted—The Carpathian oil-fields in
    Roumania and Galicia—The East Indian districts—
    The oil-fields of India and Canada—The West Indies
    —The distribution of the sources of supply.

IF the theory put forward here that petroleum
is the product of the delayed decomposition
of marine growths of the Carboniferous,
Tertiary, and probably even later periods be
accepted, it at once becomes clear that it
must be far more widely distributed through-
out the world than any one imagined possible
fifty years ago, and the whole trend of modern
experience is to show that although there
are undoubtedly limitations to prolific oil-
fields, yet very few countries exist in which
small quantities are not attainable.

Even in England deep wells at Willesden
and near Newark have shown fair traces of

oil, and it is by no means improbable that remunerative quantities may yet be found at greater depths, and the discovery of a fairly good oil supply in the Mother-country would be of such vital importance to the Empire that every clue should be followed up. In our colonies we know that with proper development enormous supplies of oil could be obtained—Burma contains one of the richest oil fields in the world, and a fair amount of activity is being shown in its development; in Trinidad, also, the whole of the south-western portion of the island is underlaid with oil; Barbadoes will one day add its quota to our Imperial supply; and many oil deposits in Canada are only waiting proper facilities to be opened up. In New Zealand, Australia, Egypt, in our West African colonies, in Newfoundland, in Assam, in the Punjab, and in Baluchistan oil undoubtedly exists; and if our Government would institute a department to encourage and, where necessary, exploit and aid oil development in our over-sea Empire, the country would soon be independent of supplies that might fail in time of war.

Until the middle of the last century vegetable and mineral oils only had been used for

burning purposes—colza, olive, and sperm oils being used in lamps—and the idea of using oil for the production of heat as well as light had never arisen, owing to the price of these products.

In 1849, however, thin streams of oil were found leaking from the shale measures in the Riddings Colliery, near Alfreton, and on distilling off the more volatile portions this oil was found to leave a thick residuum, which proved to be an excellent lubricant for machinery. The lubricants employed up to this period had been, like the lamp oils, artificially prepared from either animal or vegetable materials, and it had been found that the acid products due to oxidation were a drawback to their use. The lubricant prepared from shale oil, being free from these and other objections, at once commanded the market, but, unfortunately, the supply proved inadequate to the demand; and James Young, who had been experimenting on the subject, reasoned that, as the Alfreton oil sprang from the shale measures, it might be possible to produce it in quantity by the distillation of shale at a low temperature, and on experimenting he found that some of the Scotch shales yielded him large supplies of oil in particular.

For the first few years the lighter portions of comparatively low distilling point were practically a waste product, and were sold as such at extremely low prices, the heavy lubricating oil being the portion desired; but Young found that these lighter portions were being bought up and shipped to Hamburg, and further inquiry showed that from there they were sent to Berlin and other parts of Germany, where they were being burnt in lamps of special construction. Young having obtained samples of these lamps, had them made in Edinburgh, and the so-called mineral oil-lamp became an important factor in domestic lighting, and prepared the public mind for the burning of oil as soon as the supplies became sufficient to allow of its being done economically.

At the earliest periods of which we have record those districts of the world which have yielded the greatest volumes of petroleum were recognised as containing oil, and in the first records of fire-worship the eternal fires at Baku find mention; whilst the curative properties of the oil obtained from the springs in this district for mange, skin diseases, and rheumatism were recognised at a very early date. Later it was found in America

that the Indians from time immemorial had
been in the habit of collecting the scum from
ponds and swamps in Pennsylvania and
utilising it for the same purposes, and for
many years the oil was collected by dragging
the surface of the pools with flannel rags
and wringing these out, the oil so obtained
being sold by quack doctors in New York as
a specific for rheumatism.

It was in 1859 that, whilst sinking a well for
brine at Oil Creek, Pennsylvania, Colonel
Drake obtained oil in quantity, his well yield-
ing about 2000 barrels during that year,
and this led to a rapid development of the
district; all the available land near the creek
and along the Alleghany being acquired, an
enormous number of wells was sunk. Very
large volumes of oil were obtained, although
at a much greater depth than had been the
case with the original well, which had struck
oil at a depth of 69 feet.

For the first two years these wells yielded
only a moderate supply, and had to be
pumped; but in 1861 oil was struck at a
depth of 460 feet, under a pressure which
caused the well to flow, and this well yielded
300 barrels a day, whilst other wells in the
same neighbourhood yielded up to 2500

barrels a day. These finds of petroleum
started what was known as the oil fever in
America, and petroleum being prospected for
in every direction, many districts were found
to yield it, and wells were sunk in such num-
bers without proper provision being made for
collecting the oil that enormous losses of oil
resulted; but in spite of this, the amount
obtained was so great as to swamp the
demand, the price falling to a point which
checked the activity. In many cases the
barrels cost more than the oil, and the latter
was allowed to run to waste; and it is com-
puted that in Pennsylvania alone, in 1862, over
10,000,000 barrels of oil were run down the
streams; whilst the wooden cities which had
sprung up in the neighbourhood of successful
oil fields became deserted as the market, and
then the supply, began to fail, owing to the
producing power of these pioneer wells being
limited to periods of from six months to two
years.

At this time Western Virginia, Tennessee,
Illinois, Kentucky, Kansas, and Texas all
proved to contain oil fields; whilst in Canada at
this same time enormous yields of petroleum
were obtained, and wells were sunk in large
numbers, but the absence of any market for

the oil led to most of it being run to waste. Slowly, however, a demand for the oil was created, and being exported in bulk, the price gradually rose again; and as soon as the value of oil began to be recognised in Europe, the Russian oil fields began to be worked, and entered into competition with those of America.

Up to 1872 but little importance had been attached to the large volumes of oil that were known to exist in the Baku district in Russia, and the oil production of that region was practically a monopoly in the hands of a trader named Meerzoeff. The Russian Government, however, in this year withdrew his concession, and substituted a tax on the oil produced, and this in conjunction with the demand for oil rapidly resulted in the exploitation of the district.

In 1872 most of the oil wells which had been sunk in the Apsheron peninsula, on which Baku is situated, were shallow, and had to be pumped or bailed, but later on richer strata were struck with the result that oil was obtained under such pressure as to spout in quantities beyond control, and here again the criminal loss which has marked the inception of nearly all the great oil fields showed itself.

Since that period it has been discovered that oil is by no means confined to these great original fields, but that its distribution is fairly general, and it will be as well before going .on to review shortly the productive powers of the oil fields now known to exist.

The world's output of petroleum is now approaching the enormous annual total of 50,000,000 tons, which is made up of supplies drawn from the following countries: the United States of America, Russia, Mexico, Dutch East Indies, Roumania, Galicia, India, Japan, and Germany, the importance of their contributions being in the order given, whilst a large number of small yields from nearly every other country goes to make up the total.

United States of America.—These fields, which were the first to supply oil in quantity, to-day yield over 60 per cent. of the world's supply; and whereas in 1860 the output of half a million barrels (35 gallons Imperial) seemed an astounding quantity, to-day the output is over 200,000,000 barrels.

The Pennsylvanian and New York districts, in which oil was first discovered in quantity by Drake, were the only source of the supply

until 1875, when Ohio, West Virginia, and California began to add to the supply. Ten years later Kentucky and Tennessee added their quota, whilst Colorado, Indiana, Illinois, Kansas, Texas, and Missouri commenced oil production with the end of the last century.

This century has seen the gradual decline in production of the original field made up for by the enormous flood of oil from the Oklahoma field and the fine production from the Louisiana fields. The Eastern Illinois oil field, which, although producing in small quantities as early as 1890, became prolific only in 1905-6, has proved one of the richest yet developed, and the western side of the Illinois basin, which is almost identical in formation and oil-bearing sand, and with similar anticlines to the eastern field, is now being developed. California has steadily increased in its production, and, together with the Oklahoma and Illinois fields, yields the bulk of the American production at the present time.

Russia.—It was only when the exportation of American oil to Europe made a market for petroleum that the Russian oil fields began to be developed, and so wonderfully prolific did

the wells bored in the Baku district prove them-
selves to be that, as Mr A. Beeby Thompson
has pointed out, between 1898 and 1901
Russia produced about half the world's
supply of petroleum—a result the more
remarkable when it is considered that the
Russian production was obtained from about
2000 wells spread over an area not exceeding
ten square miles, whereas the other half of
the world's output was obtained from tens
of thousands of wells spread over many
hundreds, if not thousands, of square miles
of oil fields.

It is quite clear that if an oil field consists
of a deposit of oil stored in a porous reservoir
of sand or limestone, the quantity cannot be
unlimited, as many authorities pretend to
believe, and that the multiplication of the
wells crowded into a small area must of
necessity lead to the more rapid exhaustion
of the oil supply in that district. Every oil
district has taught the same lesson, and the
Baku field is as plain an example of it as
could be desired.

The Baku fields are situated on the Apsheron
peninsula, which juts into the Caspian Sea,
and consist of the Balakhany, Romany, and
Sabuntchi areas, about ten miles to the

north-west of the town of Baku, and the Bibi-Eibat field a few miles to the south.

In 1901 this district had reached its maximum production, and was yielding nearly 11,000,000 tons of oil per annum. The production then began falling off, and this decline being accentuated by riots and other troubles, the yield in 1905 was below 7,000,000; a slight recovery then took place, but in spite of a large increase in the number of wells, the output has again steadily fallen, and there is little doubt but that this particular district is getting exhausted.

It must be remembered, however, that the so-called Baku field is only a few square miles in an enormous district, most of which may be expected to yield oil when properly prospected and worked; and even close to the present fields, Holy Island, and to the west of the Balakhany field, Binagdi, are yielding oil. The Grosny fields, to the north of the Caucasians, yield great volumes of oil, whilst the Maikop and Taman districts have figured largely in print. The Caucasian Mountains, which form the backbone of Asia Minor, extend from the Apsheron peninsula on the Caspian shore in a north-westerly direction for something like 500 miles to where the Taman

peninsula abuts on the Kertch Straits con-
necting the Sea of Azov with the Black Sea,
and here oil lands of great promise exist
along the coast of the Black Sea to Anapa,
and there are plenty of signs to show that in
the days to come the foothills of the Caucasians
from Taman to Baku will yield a harvest of
oil.

Following the line of the Caucasians across
the Caspian Sea one finds the island of
Cheleken, celebrated for its naphtha wells,
where important supplies of oil have recently
been struck; and farther east on the Caspian
Sea coast is the Nephtiania Gora oil field,
of large extent, reaching for many miles
along the coast, and at present almost un-
touched, which many authorities expect will
prove as prolific a district as the Apsheron
peninsula, the whole district abounding in
naphtha springs, bitumen, ozokerit, and mud
volcanoes. To the north of the Caspian are the
Ural-Caspian and Emba districts, from which
investors expect much, whilst in the same
direction there are signs of other useful
fields. Leaving the Caspian and Caucasian
district, the other great oil fields of Europe
are grouped around the Carpathians, and
following the north-eastern slopes of the

Carpathian Mountains we find the oil fields of
Galicia, Bukowina, and Northern Hungary.
In the Galician fields the Boryslav district has
in the past played the most important part,
but the wells often have to be bored to a
depth of between 3000 and 4000 feet before
the rich oil-bearing strata are reached, the
overlying strata consisting largely of Miocene
marls, which contain in places consider-
able deposits of ozokerit. In this district,
again, one sees the gradual exhaustion of
the supplies, the wells which used to be the
most prolific now being almost exhausted,
whilst the number of wells sunk at the other
end of the field has to be increased to keep
up the supply.

The Austrian Government has of late
greatly helped the Galician industry by
taking nearly half the output, and, after
refining, to obtain the 'petrol' and lamp
oil, using the residuum for the navy and
railways.

The Roumanian fields are in reality a con-
tinuation of the Galician oil districts, and lie
along the south-eastern slopes of the Eastern
Carpathians. Like the Boryslav fields, the
great oil deposits at Bushtenari have begun
of late to show a falling off in the quantity of

oil produced; but the wells have not been taken to the same depth as in Galicia, and new wells bored to a greater depth in the Bordeni district, to the south of the Bush-tenari. field, have been giving good yields, whilst the Moreni, Compina, Tzintea, and Baicoe fields show considerable increase.

The Carpathian and Caucasian Mountains thus give the great oil fields of the Western Hemisphere, and when one speaks of the exhaustion of any particular area or field, it must always be borne in mind how infinitesimally small the exhausted areas are as compared with the thousands of miles of petroliferous district that flank these two great ranges. It may be that the most prolific and most easily obtained supplies have been tapped, but there is no doubt as to the vast store still existing.

The Mexican fields, which until quite recently were hardly heard of, have during the past two years come to the front, and at the end of 1912 brought Mexico into third place amongst the oil-producing countries of the world. At present the most productive of the fields are in Northern Vera Cruz and the isthmus of Tehuantepec; and as development is proceeding rapidly, pipe lines being

laid and wharves constructed at Tuxpan and
Tampico, whilst a fleet of seagoing oil ships
is undergoing construction, it is certain that
Mexico will play an important part in the oil
supply of the next twenty years.

Leaving these fields, the next area in order
of production is the Dutch East Indies, where
Borneo, Sumatra, and Java all contain oil,
and produce something over a million and
a half tons of oil per annum, the Sumatra oil
especially being very rich in hydrocarbons of
low boiling point, which makes it a valuable
source of petrol.

Our Indian possessions contain some of the
most important oil territories of the Empire.
In Burma, about 300 miles north of Rangoon
and close to the Irawadi River, very good oil
is obtained in large quantity and at a moderate
depth; and as considerable activity is being
displayed over the district, the output, which
at present amounts to over 5,000,000 barrels
per annum, will soon become of greater
importance, whilst vast tracts of country
still remain to be developed. Assam also
has an oil field at Digboi on the Brahma-
pootra River, whilst in the Punjab and
Baluchistan everything points to valuable
deposits existing.

Although prospecting for oil in Canada was carried out in the earliest days of the oil fever, and considerable yields obtained, the market was so limited and the cost of transport so high that, in spite of oil being located in many parts of the country, its production has been carried out chiefly in Ontario. The wells are comparatively shallow, and the oil is, unfortunately, contaminated with sulphur. Oil is also known to exist in New Brunswick, Alberta, Athabasca, and British Columbia.

Amongst our Colonies, the West Indian Islands of Trinidad and Barbadoes will some day prove important sources of oil supply, but progress in their development has been very slow. In Trinidad, however, several companies are actually at work, and good oil in quantity has been proved; but although wells are easy to drill, the nature of the strata has given rise to some trouble from stoppage of the wells by sand brought into the bore by the oil.

The whole of the eastern half of the island is rich in oil shows, and wells in the neighbourhood of the Pitch Lake are giving very fair yields, but it is quite likely that the main oil strata will be struck at greater depths

than those to which wells have been at
present bored.

The importance of the various countries as
a source of oil can be best judged from the
following tabulated statement of the world's
production for 1912 :—

	Millions of Tons.	Percentage
United States . .	31·4	62·8
Russia . . .	9·0	18·0
Mexico . . .	3·2	6·4
Roumania . . .	1·8	3·6
Dutch East Indies .	1·35	2·7
Galicia . . .	1·1	2·2
India . . .	1·05	2·1
Other Countries . .	1·1	2·2

CHAPTER III

THE RECOVERY AND REFINING OF
PETROLEUM

The indications of a petroliferous district—Seepages of
    oil—Natural gas—Mud volcanoes—The selection of
    a site for boring—Drilling rigs—Boring a well—Casing
    a well—Depth of wells—Gushers—Flowing wells—
    Pumping and bailing—The refining of petroleum—
    Engler's classification—The value of the fractions—
    The variations in crude oils—The ultimate composi-
    tion of crude oils—Refining—Intermittent and
    continuous distillation—The cracking of oils—The
    action of heat and pressure on naphthenes and
    paraffins—Condensation—Purification—The removal
    of sulphur—Frasch's process.

THE discovery of an oil field is brought about
far more often by chance indications than
by geological surveys; but when once the
presence of oil in a district has been ascer-
tained, the aid of the geologist becomes of
paramount importance.

  The surface indications, apart from seepages
of oil, escape of natural gas from the soil,
outcrops of oil-bearing strata, or deposits of
bituminous character, are practically nil;
but when any of these indications occur, the

geologist can generally determine if the likeli-
hood of oil existing in quantity is sufficiently
good to justify the expense of putting down
a bore and the most likely spot in which to do
so.   At one time great stress was laid on the
non-existence or stunted character of the
vegetation in a petroliferous district;   but
although some fields are barren wastes, any
one who has visited the Pitch Lake at La
Brea, in Trinidad, and seen fields of pine-
apples in its close proximity, with belts of
luxurious foliage flourishing within a few
yards of it, will realise that it is by no means
a safe factor to judge by, and is rather an
indication of shortage in rainfall than of
abundance in petroleum.

   Oil scum on streams or pools, and the
infiltration of traces of oil into wells being
sunk for water, have been, perhaps, the most
prolific causes of discovery, whilst the escape
of natural gas from a fractured anticline,
passing through wet alluvial and churning
it up so as to form a mud volcano, has always
been looked upon as a sign favourable to
the presence of oil.   Warm sulphur springs
frequently occur in districts rich in oil, and
water containing sulphuretted hydrogen is
often struck when boring for oil, and also

found with the oil in wells that are approaching exhaustion.

When the strata have been much disturbed there is sometimes an outcrop of oil-bearing sand or limestone which, if recognised, will generally show traces of oil a few feet from the surface, whilst the existence of asphaltic and bituminous deposits, formed by the oxidation of petroleum escaping from disturbed strata, is often a valuable indication.

An oil district having been located from some of these indications, the most favourable position for an experimental bore-hole has to be determined by an experienced geologist, after carefully mapping out the configuration of the strata in the surrounding area.

Where the structure of an anticline shows its form and gives an indication of the inclination of its sides on the surface of the ground, the choice of a position for boring is not difficult; but when, as in many cases, the position can be inferred only from such indications of formation as can be collected from outcrops and exposed surfaces at some distance, the matter becomes far more difficult.

The position of the well having been determined, the next step is to decide the form of

drilling plant or 'rig,' as it is generally called,
and this is determined largely by the strata
through which the bore has to pass, with the
result that each district uses the 'rig' best
suited to the local conditions.

The general outline of the well-sinking
operations is to erect first a derrick on a
firm foundation. This consists of a tapering
framework some 60 to 80 feet in height, the
base being about 20 feet and the top about
4 feet square, the top carrying two pulleys
working in bearings. Over one pulley passes
a manilla or wire rope to carry the chain of
drilling tools, whilst the other is for the rope
carrying the sand-pump, or bailer, employed
to remove detritus, water, etc., from the bore
as it is formed.

At the base of the derrick, and under the
pulleys, a shaft, 8 or 10 feet square, is sunk
through the surface-soil to the bed-rock,
unless this be too deep, in which case a 'drive-
pipe' is driven in. The necessity for this is
that the string of drilling tools is about 60
feet in length, and must have a bore to keep
them vertical before they can be worked;
and if the hole is not deep enough, it has to
be 'spudded out' to the necessary depth.
Having reached the bed-rock, the heavy

string of tools suspended by the rope is
lowered into the bore-hole, and a reciprocating
motion is given to the rope by the 'walking
beam' fixed to a strong upright and worked
by a band wheel driven from a 15-h.p. engine,
the string of tools being attached to the
beam by the 'temper-screw.' The string of
tools consists of two parts connected by a long
double link, called 'the jars'; the lower portion
is formed by the heavy iron auger stem
carrying the bit, whilst the upper consists of
the sinker bar.

The motion of the walking beam raises the
string of tools and drops them again on the
bottom of the bore, whilst the links slide over
each other, and as the beam rises again 'the
jars' impart a jerk to the tools, which loosens
them if the bit has become embedded or
stuck. After a certain depth has been bored
the tools are raised and suspended in the
derrick whilst a freshly-dressed bit is put on,
and in the meantime the sand-pump or
bailer is lowered by the second rope passing
over the other pulley to remove the detritus
left by the drilling and any water that may
have leaked in.

The drills used vary very much in character
according to the nature of the strata, and the

operation proceeds day and night, the beam
giving the rise and fall to the string of tools,
whilst the driller, by means of a lever inserted
in the temper-screw, gives it a rotary motion.
Great delay is occasionally caused by the
breaking of a rope or the tools themselves,
in which case grapplers or fishing tools have
to be lowered into the well to recover these
at the bottom, an operation of considerable
difficulty.

This method of drilling is called the 'cable
system,' owing to the use of manilla rope or
steel cables, and is the one most used in
America; but another and perhaps more
popular system is the 'Canadian rig,' in
which the rope is replaced by ash poles
screwed together in lengths; and the rig most
used in Roumania and Galicia is a modifica-
tion of this, iron rods replacing the ash
poles. The advantage of a rod system is that
by means of a turn-table at the mouth of the
bore a positive rotation can be given to the
drill, whilst in the cable system it is only the
torsion of the rope which does this. In Russia,
owing to the width of bore necessitated
by the nature of the strata, square iron rods
are employed. In some fields, like the Texas
and Louisiana districts, where running sands

are encountered, flush systems are employed, in which water is pumped down the casing, whilst flushing bits are often used, consisting of steel chisels attached to hydraulic hose so arranged that a powerful stream of water is ejected on to the edge of the drill.

Whatever the rig adopted, as the boring proceeds the well has to be cased to prevent caving in of the sides and to keep out water. Where the well is not more than a foot in diameter, and water in the strata through which the bore passes has to be kept out, lap-welded iron or steel tubing is used, the ends being screwed to give a water-tight casing; when, however, the well is over a foot in diameter the cost of this would be too high, and in the Baku and Roumanian fields riveted casing is chiefly employed. The bore of an oil well has to be made of about three times the diameter at the top as that required at the bottom, if it is to be anything like 2000 feet in depth, since the column of casing, as a rule, can only be continued of the original size for a few hundred feet, the next column having to be small enough to enable it to pass through the upper casing.

The depth to which wells have to be taken

to reach the oil strata varies with the locality,
the Galician wells being of great depth and
often carried to from 3000 to 4000 feet; whilst
in some countries, especially in new fields, the
depth may be only a few hundred feet. The
cost of casing with deep wells is very great,
and in the Baku field alone it has been calcu-
lated that 700,000 tons of casing have been
used.

In a new district the first wells sunk often
obtain a good yield from the first oil horizon,
and, in consequence, are of moderate depth;
but as the upper strata become exhausted,
the wells have to be drilled to a greater and
greater depth. A good example of this is
seen in the Balakhany-Sabuntchi fields at
Baku, where in 1873 the average depth of the
wells was 154 feet, and in the next ten years
rose, or rather sank, to 400 feet, was 1125
feet in 1903, and now is 2000 feet.

When an oil-yielding stratum has been
reached in a virgin district, it is often found
that the pressure of gas in the crown of the
anticline is great enough to drive the oil up the
bore with a force that carries all before it, and
produces a fountain perhaps 200 or 300 feet
in height. An uncontrolled gusher of this
kind invariably means a great waste of oil

and often a serious danger to surrounding property, as the spray, if there is any wind, may travel a long distance, and becoming ignited at a boiler furnace cause a fire almost impossible to extinguish. When a gusher of this kind is struck, a massive iron block, bolted at an angle of 45° to massive timbers, is slid above the issuing jet, which is thus deflected against a wooden palisade, down which it streams into channels that take it to a sump pit or reservoir. In some districts like the Baku in the old days, the oil is so highly charged with sand that a big gusher would, by sand-blast action, cut through the chilled steel shields in a few days.

In other districts, like the Roumanian, a new well will gush at first, and after a time, the pressure being relieved, the oil rises only to a certain height up the bore, and has to be bailed or pumped. When the oil contains but little sand, a force-pump is lowered into the oil, and the plunger is worked by rods actuated by the walking beam; but if the oil contains much sand, like the Russian oil, it has to be bailed. The bailer is a cylindrical vessel a little less in diameter than the casing of the well, and from 10 to 60 feet in length.

The bottom is closed by a valve with an elongated spindle projecting below the bottom of the bailer, so that when it is lowered to the bottom of the well, the spindle is pressed up and opens the valve, the oil flowing in and filling the vessel; but on raising the bailer the valve closes and the oil is brought to the surface.

The foregoing description of oil field practice is necessarily of the barest possible kind, and is intended only to give an idea of the difficulties to be surmounted in the winning of oil. Full particulars will be found in Sir Boverton Redwood's monumental work on *Petroleum and Its Products*, or in Beeby Thompson's excellent book on *Petroleum Mining*.

It has already been pointed out that crude petroleum as obtained from the well is a mixture of many hydrocarbons, varying in their proportions and to a certain extent in their nature with their source, and with the factors of time, temperature, and pressure under which they have been formed, but all having characteristics in common, which enable the refiner to subdivide the crude material into portions fitted for the different uses to which they are to be put.

The possibility of doing this is dependent upon the different temperatures at which the constituents of the crude oil can be distilled off from the mixture as vapours and recondensed. to liquids on cooling. The hydrocarbons most easily distilled, *i.e.* at the lowest temperature, are the bodies used for cleaning and as 'petrol' in the internal combustion motor; a slightly higher distilling temperature yields the solvents; when these have been distilled off, a further rise in temperature brings over the lighting oils for use in oil lamps; after these the solar oils used for gas-making distil over; and when these have been eliminated lubricating oils are obtained, leaving behind a pitch-like residue that is used for asphaltic coatings; whilst if the temperature is pressed to a still higher degree, a further distillate is obtained and coke left in the retort.

Where the demand for fuel oil is great the distillation is stopped after the lighting oil has distilled, and the oil remaining in the retort, called 'Ostatki' in the Russian distilleries and 'Residuum' in America, is used for fuel.

Anything approaching a complete separation of the multitude of hydrocarbons present

in a crude petroleum would be commercially
impossible; indeed, the nearness of the
boiling points of some of the bodies present
and the formation of mixtures which distil
over together make it one of the most
laborious and difficult operations that can be
attempted in the laboratory; but by frac-
tional distillation on a large scale the refiner
produces mixtures between fixed limits of
specific gravity and boiling point, which are
recognised by the trade and sold under
various names, such mixtures having the same
characteristics which fit them for certain
purposes, although they may be mixtures of
totally different hydrocarbons.

A convenient rough classification is that
suggested by Engler, which consists in taking
the percentage of crude oil that distils up to
a temperature of 150° C. (302° F.), which
fraction contains the cleaning spirit, petrol,
and solvent naphtha, and is generally spoken
of as 'benzine.' The temperature of the
residue is then slowly raised to 300° C. (572° F.),
and the fraction coming over between 150° C.
and 300° C. is that used as illuminating oil
and called kerosene, whilst the residue is the
fuel oil.

The value of a crude oil, of course, depends

largely upon the fractions which it contains.
Before the advent of the internal combustion
motor the most volatile fractions had but
little use save as grease solvents, the power
which they possess of dissolving grease and
fat and so liberating the dirt glued by these
to the surface of fabrics making them valu-
able for 'dry cleaning.'   The market for
this purpose was, however, limited, and
the illuminating oil and lubricants were the
products that gave the best returns, the
ostatki or residuum being almost waste
products.

When, however, the motor-car began to
create a demand for petrol, attention was
turned to the increasing market for the more
volatile fractions; whilst the introduction of
oil fuel created a large and ever-increasing
market for the residues, which in the early
days of the oil industry used often to be
burnt to waste as the easiest way of getting
rid of them; so that to-day the decreasing
market for the illuminating oil and the
enormous demand for the light and heavy
fractions have entirely revolutionised the oil
market.

In considering the relative value of the
various sources of oil supply, it is clear that

considerable attention should be given by
the investor to this side of the question; and
that not only should the character of the oil
as regards the fractions that it will yield be
taken into account, but also the purity of
the oil as regards sulphur, some oils being
rendered almost valueless by the presence of
sulphur compounds, which must be reduced
to a very small percentage in order to fit it
even for fuel purposes, the cost of doing which
may be often a serious factor in the price of
the oil.

The characteristic yields of the fractions
from crude petroleum and the way in which
they vary is well shown in Table I., p. 76,
taken from Beeby Thompson's *Petroleum
Mining.*

A glance at this table shows the value of
the specific gravity of the crude oil in indicat-
ing to a certain extent its characteristics,
those having a specific gravity of over 0·9
yielding but little of the more volatile con-
stituents, whilst those below 0·85 contain
them in notable quantity.

Oils from the same neighbourhood often
vary considerably in the percentages of the
fractions obtained from them. Taking as an
example the Baku fields of the Apsheron

peninsula, Engler obtained the following
results :—

	Balakhani-Sabuntchi.	Bibi-Eibat.
	Sp. gr. 0·865 to 0·870	0·855 to 0·858
	Per cent.	Per cent.
Benzine . .	5 to 6	10·5
Kerosene . .	27 to 33	40·0
Solar distillate .	5 to 6	13·5
Residue (ostatki) .	50 to 60	36·0

Even greater variations are often found,
but still the different oils from a district
have a fairly close resemblance if drawn
from the same strata ; but in the same way
that in some of our coal fields the seams
vary from a steam coal to a highly bituminous
one, it is to be expected that the oil from
different strata of an oil field will vary in the
nature of their constituents, although in fact
the variation is not so great as with coal.

In spite of these differences in the per-
centages of the various distillates obtainable
from the crude oils, the ultimate ratio of the
carbon and hydrogen in the crude oils shows
but little difference, as is evidenced by the
following table of analyses by various
observers :—

TABLE I

COMPARISON OF REPRESENTATIVE CRUDE PETROLEUMS FROM DIFFERENT OIL FIELDS

FIELD FROM WHICH OIL IS TAKEN.	DISTILLATE IN VOLUME.					
	0° to 150° C.		150° to 300° C.		300° C. and above.	
	Sp. Gr.	%	Sp. Gr.	%	Sp. Gr.	%
Pennsylvania	0·820	21·0	0·718	41·0	0·798	87·0
Ohio (Lima)	0·838	9·7	0·728	37·1	0·787	52·12
Illinois (Randolph County)	0·842	14·0	0·729	37·0	0·797	49·0
Kansas (Wilson County)	0·835	19·0	0·720	38·1	0·808	42·8
Oklahoma (Glenn Pool)	0·846	8·5	0·756	42·0	0·800	49·9
West Virginia	0·787	16·5	0·711	41·0	0·769	34·5
California (Coalinga)	0·915	5·7	0·771	34·1	0·858	60·2
„ (Kern River)	0·961	—	—	20·2	0·862	79·8
„ (Los Angeles)	0·971	—	—	26·8	0·885	78·7
„ (Whittier Field)	0·929	4·2	0·778	38·3	0·870	57·5
Texas	0·910	2·9	0·794	39·8	0·876	57·3
Russia (Grosny)	0·869	13·4	0·730	25·6	0·808	60·6
Roumania (Bushtenari)	0·842	35·4	0·734	29·8	0·840	34·8
„ (Compina)	0·824	37·7	0·729	30·5	0·823	31·8
Burma (Yenangyat)	0·840	17·8	—	40·4	—	—
Italy (Villeia)	0·787	55·0	—	42·0	—	—
Japan (Echigo)	0·862	21·8	—	38·8	—	39·9

TABLE II

ULTIMATE COMPOSITION OF REPRESENTATIVE PETROLEUMS

Origin of Petroleum.	Specific Gravity.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.
Pennsylvania	0·801	86·10	13·90	—	—	0·06
Ohio	0·827	85·42	14·59	0·064	—	—
California (heavy)	0·084	86·32	11·70	1·25	—	0·84
,, (light)	0·846	86·24	13·08	—	—	—
Texas (Beaumont)	0·912	85·03	12·30	0·92	—	1·75
Roumania (Bushtenari)	—	86·30	13·32	—	—	0·18
,, (Compina)	—	86·03	13·26	—	—	0·13
Canada (Petrolia)	—	88·94	13·87	—	—	0·99
Peru (Zorritos)	0·850	88·08	13·06	0·071	0·748	0·041
Italy (Parma)	0·786	84·00	13·40	—	1·80	—
Russia (Baku)	0·884	86·3	13·6	—	0·1	—
Galicia	0·852	85·3	12·6	—	2·1	—
Burma	0·855	88·8	12·7	—	3·5	—
East Indies (Java)	0·880	87·1	12·0	—	0·9	—

As the calorific value of these crude oils
depends upon the ratio of combustible ele-
ments that they contain, it follows that the
variation in their heating value as fuels
differs but little. The crude oil, however, is
never used as a fuel far from the producing
areas, as the danger in use and transport is too
great, owing to the volatile portions that most
of them contain. In the early days of the
industry much crude oil was exported from
the producing districts, and was refined,
i.e. fractionated and purified in the country
using the products; but the danger of ship-
ment and the alteration in market conditions
have put an end to this, save in countries
like France, where there is a heavy import
duty on petrol and a low one on the crude oil,
and most of the important oil fields now refine
the crude oil in the locality in which it has
been produced.

The general procedure is to convey the
crude oil from the well by a short pipe line
to the refining works, where it is stored in
tanks, and the sand and water with which
it is nearly always mixed allowed to separate
by gravity. In some cases it then travels to
a smaller tank containing pipes, through which
the hot residues from the stills pass; heating

the oil before it reaches the stills to about
the boiling point of water.

The stills employed vary with the grade
of crude oil. Those largely used in America
with oils rich in low boiling-point fractions
consist of a horizontal cylindrical boiler
with a dome, from which a broad vapour-
pipe leads the distilling vapours to the
condensers; whilst in Russia continuous
distillation is used in many localities, the
stills being arranged in series, each unit
being at a slightly lower level and heated to
a higher temperature than the preceding one.
In this process the oil enters the first still,
which is kept at a constant temperature, and
as it loses all constituents distilling at the
temperature of the retort it flows into the
next still, where the heat is greater, and so
throughout the series; and as a steady flow
of oil into the first retort is kept up, each
retort in this way yields a constant product
corresponding to the temperature of the still.
The difference in the two processes consists of
the fact that in the 'Intermittent' the retort
is charged at a low temperature and the heat
is raised to the highest temperature required,
the residue being then discharged and the still
again filled, whilst in the 'Continuous' each still

is at a constant temperature, the oil flowing
in at one end of the series and the residue
escaping from the last and hottest still.

When oil is distilled at a slowly rising
temperature, the various constituents of the
oil vaporise as their boiling points are
reached, and if conducted away to a cooled
condenser again become liquid, with very
little change in composition; but if vaporisa-
tion is retarded by the operation being carried
out under pressure, or if the vapour is kept
in the heated zone after it has been given
off, changes in chemical composition will
often take place ; whilst if the oil vapour
is exposed to contact with highly-heated
surfaces decomposition to compounds of lower
boiling point and gaseous products may ensue,
an operation technically known as 'cracking.'

As an extreme instance of such decom-
position, we may take the manufacture of
carburetted water gas, in which solar oil (the
fraction distilling immediately after the lamp
oil has come over) is vaporised in a stream
of hot-water gas, made by passing steam
through incandescent coke, and consisting of
nearly equal volumes of hydrogen and carbon
monoxide, the mixture then being passed
through a chamber containing red-hot brick

work, contact with which decomposes the oil into hydrogen and gaseous hydrocarbons, the latter giving the non-luminous water gas the property of burning with a luminous flame and enabling it to be used to add to the volume of coal gas.

Oil gas, such as is used for railway-carriage lighting, also is made by allowing such oil to drip into an iron retort heated to a dull red heat, when it is converted into a rich illuminating gas.

Such processes consist of decomposition of the original hydrocarbons with the formation of simpler gaseous bodies, such as methane, ethylene, ethane, and propane, whilst hydrogen is at the same time set free.

As early as 1871, however, Thorpe and Young showed that if solid paraffin be heated under pressure it is converted into a mixture of liquid hydrocarbons of lower boiling point, and but little gas is evolved; and it has been found that in distilling oil this action takes place to a certain degree, so that by carefully regulated distillation under pressure the volume of the fractions of low boiling-point oil can be augmented by the cracking of some of the higher fractions.

The change taking place varies with the

character of the oil; if naphthenes of the character of those found in Russian oil are passed through heated tubes, they shed off hydrogen and form aromatic hydrocarbons, thus—

Naphthene.	Aromatic Hydrocarbon (Benzene).	Hydrogen.
C_6H_{12} =	C_6H_6 +	$3 H_2$
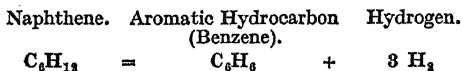
whilst if a paraffin, such as those constituting the American oil, be distilled under pressure, it breaks up into a simpler member of the paraffin series and into an unsaturated hydrocarbon.   In order to induce actions of this character and cause hydrocarbons to condense on the roof of the still and drop back into the boiling liquid, the crown of the still is often left unlagged, this being found to add to the volume of lighter products obtained.

If, on the other hand, it is desired to avoid any such changes, the air pressure in the still is reduced in order to effect the distillation at the lowest possible temperature.

Frequently steam is passed through the distilling oil in order to carry over the vapours rapidly to the condenser and prevent them remaining in the heated zone ; and steam also acts in preventing decomposition at moderate temperatures by dilution of the vapour.   At a high temperature, however,

steam and oil react upon each other with formation of hydrogen and carbon monoxide.

In the intermittent distillation of oil the usual practice is to distil off the light and illuminating oil fractions at one operation, and to submit the residue to a further distillation in a separate retort for the solar and lubricating oil fractions.

In order to condense the vapours leaving the still, they are passed through coils or grids of pipe of sufficient section to prevent their choking by deposition of solid paraffin and to present a large cooling surface. Water flowing around the pipes is the usual cooling medium, but sometimes the condenser is used as a regenerator, and the pipes are cooled by the oil passing round them as it flows to the still. After the first distillation into fractions, the light oil generally undergoes a second fractionation in steam-heated stills, in order to obtain spirit, petrol, etc.

The fractions of definite ranges of boiling point and specific gravity having been obtained, they then have to undergo processes of purification, called 'refining,' in order to remove the high colour and odour which would unfit them for the market.

The usual process of refining consists in

agitating the oil with sulphuric acid, the amount of acid and time of agitation being governed by the density of the oil and its degree of purity. Heavy oils and those which have been overheated during distillation require more acid than the lighter fractions, and some oils may require several treatments.

The mixing and agitating is done in a lead-lined tank by means of air jets or mechanical agitators, and the mixture is allowed to stand until the acid and the tar-like impurities that it has separated settle out, when the oil is drawn off from above them and undergoes a treatment of the same kind with a solution of caustic soda to neutralise any acid.

One of the drawbacks to cracking oil during distillation is that the unsaturated hydrocarbons so formed require a large amount of sulphuric acid for their removal.

Sulphur, which is present in all oils, must be reduced to 0·5 per cent. at most to fit them for illuminating or even fuel purposes, and with such oils as the Pennsylvanian, Russian, Roumanian, and Galician, the treatment with sulphuric acid and sodium hydrate suffices to do this; but other oils, such as some Texan, Californian, Mexican, and Canadian oils, contain higher percentages,

and special methods of purification have to be employed. The best of these is the beautiful process devised by Hermann Frasch, which may be quoted as follows :—

To free petroleum of elementary sulphur or hydrogen sulphide presents little difficulty, but the sulphur compound which is the cause of the offensive odour presents greater resistance and cannot be easily eliminated. It was discovered that this sulphur compound possessed the peculiarity of dissolving a number of metallic oxides, and that when the oil was saturated with the oxide the disagreeable odour vanished, reappearing on an attempt to free the solution of its metal.

This solution of metal in petroleum has an intense affinity for sulphur, and if more oxide than that necessary to precipitate all the sulphur present in the petroleum is added during the course of distillation a complete desulphurisation of the petroleum is effected. It was found by experiment that copper was the most suitable metal, and this was made the subject-matter of a patent.

The process, which has been applied in several of the oil fields of America and Canada, is, shortly, as follows : The oxide of copper is mixed with the petroleum distillate in a

still supplied with suitable means of agitation.
100,000 lb. of copper oxide are used for the
first charge of 2000 barrels. After 80 per cent.
has been distilled off a new charge of dis-
tillate is added together with a further
30,000 lb. of copper oxide, followed by two
more runs, so that about 200,000 lb. of copper
material is in the still when the fourth run is
made.   The residuum is pumped through
a filter press, and the oil adhering to the solid
product burned off.   The dry mixture of
sulphide and oxide of copper is then put into
a roasting furnace, where it is desulphurised
to 1 per cent., or less.

A modification of this process consists in
passing the vapour from a still charged with
crude petroleum through two shells, each
containing a large wire steel brush revolving
at about 60 revolutions per minute in the
requisite amount of copper and heavy oil.
The vapour passes first around the shells to
prevent condensation, and then through the
shells on to the condenser. As the tempera-
ture of the vapour increases, anything con-
densed during the first period on the brushes
is re-evaporated.

In the roasting of the spent copper oxide,
difficulty was at first experienced in the

M'Dougal furnace employed, owing to the warping of the shaft and arms used for agitating the mass. This was overcome by the introduction of a hot-water cooling system, which made it possible to increase the size of the furnace, and so gave a much larger daily output of revivified oxide. After the copper oxide has been revivified it is ground, mixed with residual oil from the filter press, and pumped into the shells as required.

OIL FUEL

CHAPTER IV

THE TRANSPORTATION AND STORAGE OF OIL

Pipe lines—Tank wagons—Tank steamers—Accidents
   due to transport of spirit and crude oil—Explosive
   mixtures of petroleum vapour and air—Proportions
   necessary to give explosion—Temperature necessary
   for ignition—Leakage and travel of petrol vapour—
   The detection of inflammable vapour—The Clowes-
   Redwood vapour test—Test for petrol vapour—
   Extincteurs for petroleum fires—Flash point—The
   Abel closed flash point test—The Pensky-Marten—
   The legal flash-point for lamp oil and for fuel oil—
   The construction of tank ships—Lloyd's regulations
   —Carriage of oil through the Suez Canal—Tank
   ships fitted with Diesel engines—The Vulcanus—
   The storage of oils—The Thames Haven installation.

FROM the oil fields to the consumer is a far
cry, and it needs much careful management
to prevent the cost of transport making the
price of oil for fuel purposes prohibitive save
for special purposes for which the advantages
are so great as to make price almost a
secondary consideration.

   In the oil-producing countries pipe lines
are employed to bring the oil from the field
either to rail centres or to the seaboard
for shipment; specially constructed oil-tank

steamers then convey it to the distributing ports of the countries using it, and tank wagons and barges bring it to the consumers.

The idea of the pipe line by which oil can be pumped in stages for almost any distance originated in America about 1860, and soon the Pennsylvanian field was linked up with New York and the chief refining centres, and the total length of lines transporting crude oil from this field was approximately 25,000 miles, this of course including the network of 2-inch pipes which come from the wells to the trunk lines, and are generally privately owned.

The main pipe lines are made of lap-welded wrought-iron piping in lengths of 18 feet, screw-jointed together and provided at intervals with bends to take up any expansion or contraction. In any long length of line there have to be pumping stations to overcome the surface friction of the viscous oil, and between the Pennsylvanian field and New York there are eleven such stations.

The pipe lines are laid about three feet below the surface of the soil to protect the oil from cold; but even then stoppages occur occasionally from the deposition of crystals of solid paraffin wax or suspended matter,

and to prevent this a spindle fitted with
radial blades and vanes is forced through the
pipe with the oil. This automatic scraper,
called a ' go-devil,' rotates as it passes
forward and scrapes the pipe clean from
deposits, itself falling into a catch-box at
the end of the system.

At the wharves or railway depots to which
the pipe lines lead the oil is either stored in
reservoirs from which it can be pumped into
tank wagons, barges, or oil ships, or else is
fed direct into the tank wagons from a series
of feed pipes arranged along a platform in
such a way that a whole train can be filled in
a very short space of time. For shipping
purposes storage is practically a necessity,
the tank steamer when once alongside the
wharf having to be filled up and got away as
quickly as possible.

The tank wagons employed for railway
transport consist of cylindrical tanks, made of
boiler-plate and fitted with a dome resembling
those on locomotive boilers. The feed opening
is at the top of the dome, whilst the discharge-
valve is at the bottom of the tank. Such
wagons vary in size, but usually hold 5000
or 8000 gallons.

The shipment of crude petroleum or the

light distillates is now recognised as being so dangerous as to necessitate special methods of construction and special precautions.

Even prior to 1880 attention had been drawn to the danger of volatile hydrocarbons carried in ships by explosions on H.M.S. *Hercules, Triumph,* and *Cockatrice,* and the loss of H.M.S. *Dottrel* from leakages of volatile spirit used in making up anti-fouling compositions and quick-drying paint, so that when the carriage in bulk of crude petroleum commenced precautions were taken to safeguard the vessels as far as possible, but occasionally, even when the cargo consisted of lamp oil, from which the more volatile portions had been distilled, accidents happened, and fires and explosions on the SS. *Lux, Wild Flower, Ville de Calais, Fergusons, Tancarville, Norcross,* and others, led to extended investigations being made, and the enactments necessary to safeguard the trade being brought into force.

There are few sources of oil supply in the world in which the volatile portions are so low that the oil can be carried direct with safety, although the quantity may be comparatively small, but in some cases the mere exposure to the sun in an open tank or

reservoir will get rid of the more dangerously volatile portions.

It is the petroleum spirit and slightly less volatile portions, which we know under the name of 'petrol,' that constitute the great danger with crude oil, and these consist usually of the first three or four liquid members of the paraffin group of hydrocarbons— pentane, hexane, heptane, and traces of octane, and generally correspond in composition to heptane, C_7H_{16}.

So volatile are these liquids that they give off inflammable vapours even below the freezing-point, and one pint will give off enough vapour to render 100 cubic feet of air highly explosive. A peculiar property of 'petrol' is its power of creeping, which renders it necessary to take special precautions in storing it in vessels sufficiently vapour-tight to resist this action, otherwise the slightest leakage and evaporation would render the air in a ship's hold, cellar, or other place of storage strongly explosive.

The amount of vapour of petrol required to make an explosive mixture with air varies between 2 and 5 per cent. of the volume of air ; mixtures of 2 per cent. of vapour with 98 of air are feebly explosive, but the force of the

explosion increases as the percentage of vapour rises, and reaches a maximum at 2·6 per cent., after which point the explosive violence gradually decreases until when the air contains 5 per cent. of vapour the mixture is almost non-explosive.

Unlike the vapour of such substances as carbon bisulphide, the mixture of petrol vapour and air requires a comparatively high temperature before it will ignite, and experiments have shown that the temperature given by a platinum wire raised to a white heat, *i.e.* between 1200 and 1400°C., is needed to cause the ignition, whilst the spark on a charred piece of wood, a red-hot coal, or a spark from a flint and steel, proved insufficiently hot to cause the explosion. This is true only when the air is free from dust, as in that case even a small spark will start the explosion, due to the dust first catching fire, and this in turn igniting the explosive mixture.

The vapour of petrol is extremely heavy in comparison with the weight of air, so that its tendency is to flow to the lowest level it can find without much intermingling with the air taking place. In this way the vapour from a leak of petrol may travel for a considerable distance, and should it come in

contact with a light the vapour will be ignited
and the flame will flash back to the source of
the escape.

The dangers of the transport and storage
of lamp oils and residuum are very slight;
but it must not be forgotten that these liquids
are inflammable, and, in the case of a fire,
are liable to become ignited and increase
the conflagration. It is the crude oil and the
petroleum spirit which constitute the gravest
source of danger, and their transport and
storage call for special precautions to be
taken against the evolution and accumula-
tion of inflammable vapours. The atmos-
phere of all confined spaces where these
materials are stored should be a matter of
constant observation, especially under con-
ditions where thorough ventilation cannot be
obtained. Naked lights of course, should
never be employed in such a store, the miner's
safety lamp or a specially-protected electric
light being the only methods of artificial
illumination permissible, whilst the condition
of the atmosphere can be readily determined
by the apparatus devised by Dr Clowes and
Sir Boverton Redwood.

The safety lamp, which was the outcome of
the researches of Sir Humphry Davy and

George Stephenson, consists in its main
essentials of a flame from a small oil lamp,
the flame being entirely surrounded by a
covering of wire gauze. It was found that
although the light and gaseous products of
the combustion of the oil could pass freely
through the gauze, yet that even in an atmos-
phere containing a dangerous proportion of
fire-damp the combustible mixture might
burn inside the lamp without communicating
the flame to the outside until such time as
the gauze got red hot. Before that point had
been reached, however, the miner would have
taken the warning given by the appearance of
the flame and moved into a safer atmosphere.
With small percentages of fire-damp the
indications were not so marked, and the
presence of this dangerous gas is shown by
the appearance of a small flame-cap above the
flame of the burning oil, and the length of
this flame-cap served as a rough indication
of the proportion that was present. It is
upon this principle that our most modern
and successful methods of detecting explosive
gaseous mixtures and roughly estimating the
proportion of explosive gas have been based.

In the earlier forms of apparatus for the
detection of explosive atmospheres a luminous

flame was employed, but it soon became evident that the glare of the flame seriously interfered with observation of the flame-cap, so that various improvements were made, such as shielding the direct light of the lamp from the eye by a screen, the replacement of the gauze in the lower part of the lamp by a glass cylinder, etc. It was not, however, until the luminous flame was replaced by the non-luminous flame of burning hydrogen that any degree of accuracy was attained.

The testing lamp for miners devised by Professor Clowes was modified by Sir Boverton Redwood to fit it for analysing the atmosphere in tanks and stores used for the carriage and storage of crude petroleum and petroleum spirit in bulk. The apparatus consists of the lamp, a cylinder of compressed hydrogen, and the sampling vessel. The sampling vessel serves for collecting a certain volume of the atmosphere to be tested under uniform conditions. It consists of a compression pump fitted inside a strong metal cylinder which is provided with a pressure gauge and valve, and with the necessary connections and taps for collecting and delivering the sample. The pump is taken into the atmosphere containing the inflammable

vapour, and by working the handle the cylinder is charged to a pressure of 30 lb. to the square inch, at which pressure it will contain one-third of a cubic foot.

The lamp has a base carrying two inlet tubes for the sample and the hydrogen respectively, the latter being furnished with a regulating tap and jet. The top of the inlet tube for the sample of vapour is protected by a series of baffles and three discs of fine wire gauze, which serve to regulate the flow of the gas and prevent any flashing back of the flame into the sampling vessel. The hydrogen jet is surrounded by a metal tube, the front of which is removed, and over this slides a chimney, also of metal, fitted with a glass window on which are etched lines corresponding to various heights of flame-caps.

To make a test, the sampling vessel is filled with the suspected atmosphere, and connected to its inlet on the lamp. The hydrogen cylinder is attached to the other inlet, and, the sliding chimney being raised, the hydrogen is admitted to the jet and lighted, the supply being so adjusted as to give a flame slightly more than 10 millimetres in length. After the gas has been allowed to

burn for a few minutes, in order to drive
off any moisture condensed on the chimney,
the chimney is closed completely, and the
hydrogen flame accurately adjusted by the
regulating tap, so that the tip of the flame is
just hidden when the eye of the operator is
on a level with the bottom of the window.
To render the observations more easy the
lamp and head of the operator are covered
by a dark cloth, when the tap of the sampling
vessel is opened. Should the atmosphere
under test contain even a small percentage of
explosive vapour, a grayish-blue cap will be
seen above the hydrogen flame, and with
increase in the proportion of vapour the
flame-cap becomes sharper and considerably
elongated, and the length of this cap gives
a fairly accurate idea of the percentage of
inflammable vapour present.

Another most ingenious apparatus has
been devised by Philips and Steele for the
automatic detection of inflammable gas and
vapour. · The apparatus consists of two coils
of platinum wire, arranged in parallel in an
electric circuit, and of the same resistance.
Each of these coils is connected in series with
one coil of a polarised relay, the moving
armature of which is very delicately adjusted.

The two platinum coils are enclosed in glass tubes so arranged that the air under test can be pumped round the outside of one tube without coming in contact with the coil, passing on to the inside of the second tube, where it is brought under the influence of the second coil. The armature of the relay swings between two contacts, one connected with a lamp giving a white light and the other with a red lamp. There are various devices for indicating any accident to the platinum coils, and also for ensuring sensitiveness in the relay.

In use, the apparatus is connected with the ordinary electric supply mains, which causes the wire coils to glow, and a white light to appear in the relay circuit. The suspected air is then pumped through the apparatus by means of an electric motor; should no inflammable vapour be present, the flow of air makes no difference in the electric conditions; but should the air contain even a slight percentage of vapour the electric balance is disturbed, the armature of the relay swings over, and a red light appears. This is due to the fact that the hot surface of the platinum coil in contact with the vapour-contaminated air burns the combustible material, and so the

coil gets an increase of heat corresponding
to the percentage of vapour present. This
causes a *pro rata* rise in the resistance of the
coil, and affects the current flowing through
the relay coil, so that the armature swings
over to the other stop, which brings the red
lamp into the circuit.

The apparatus has been tried successfully
with all combustible gases and vapours, and
its sensitiveness can be adjusted to varying
conditions. For ordinary purposes it is made
to act when the air contains one-quarter the
amount of vapour necessary to render it just
inflammable, but it can be regulated to indi-
cate one-fortieth of this amount.

Should petroleum spirit by any chance take
fire in bulk, its extinction is an operation
fraught with many difficulties. Water is
useless for the purpose, as the spirit is far
lighter than water and rises to the surface,
there continuing its combustion, whilst the
cooling action of the water is rendered nuga-
tory by the freedom with which the vapour
is evolved from the spirit. Extincteurs and
gases which do not support combustion, such
as carbon dioxide and sulphur dioxide, are
useful only in confined spaces, and the best
way to extinguish the fire is to smother

the oil with sand or some such inert material.

The dangers caused by the volatility and inflammability of the vapours of the lighter portions of the oil have cut down our liquid-fuel supplies to about one-third of the total production of crude oil. As has already been pointed out, if one attempted to use the oil as obtained from the well, the lighter portions would evaporate into the air of the tank or store, and with it would form an explosive mixture, whilst the vapour, being much heavier than air, might flow from the store and catch fire at some distant flame, and the ignition would flash back to the store itself. Many accidents due to this cause took place in the early days of the oil industry before the danger was fully realised.

The temperature at which any oil commences to give off inflammable vapour is known as its 'Flash-point.' There are two methods by which this point can be determined, the tests being known under the names of the 'open' and the 'closed' test. In the former, a small quantity of the oil is heated in a cup or other open vessel, the heat being so regulated, as indicated by a thermometer in the oil, that the increase in

temperature is gradual. Periodically a small flame is passed over the mouth of the vessel, and at a certain temperature, depending on the nature of the oil, a flash is observed, due to the ignition of the vapour given off. The temperature at which this flash occurs is noted, and is called the flash-point of that oil.

This method, however, gives unsatisfactory results, as the test is readily affected by external influences, and in order to overcome these difficulties Sir Frederick Abel devised the apparatus which bears his name, and which has been adopted in England as the legal test. The oil is poured into a metal cup of standard size to such a depth that it just covers the sharpened tip of a bent wire soldered inside the cup; the cup is provided with a flange, by which it can be supported in an outer vessel forming the inner casing of a water-jacket surrounding the cup, the water in which can be heated by a spirit-lamp fixed underneath. The cup has a close-fitting lid, and carries the test-flame and thermometer; across the diameter of the lid are three square holes which can be opened or closed by a sliding metal plate in which are corresponding openings. The test-flame may be a minute jet of gas or the flame from

a small oil lamp, the size of the flame in each case being regulated to correspond with that of an ivory bead fixed on the lid. The gas jet or oil lamp is so arranged on trunnions that the action of opening the sliding plate causes the flame to be lowered into one of the openings in the lid, the normal position being resumed when the slide is closed. The thermometer is immersed in the oil to a definite distance below the surface, and a second thermometer is fitted into the water jacket for indicating the temperature of the water.

The water is kept at 130° F. by the spirit-lamp, and the temperature of the oil slowly rises. At definite intervals of time the metal slide on the lid is pulled, and the test-flame is thereby lowered into the space above the oil. As soon as a flash is seen to traverse this space the temperature of the oil is noted, and that temperature is regarded as the flash-point of that particular oil. This is known as the 'closed' test.

In Germany a modified form of the above apparatus is used, known as the Pensky-Marten. A porcelain cup is used for the oil, and this rests in an outer vessel of iron, a layer of sand raising the cup half an inch away from the point of contact with the

flame. A small fan which can be rotated by
hand is also provided to keep the liquid
agitated and the heat evenly distributed.

Marked differences are obtained when the
same oil is tested by the open and by the
closed test, a considerably higher flash-point
being obtained with the open test.

For oils suitable for domestic use in heating
and lighting and as a fuel for industrial pur-
poses on shore, the flash-point of an oil has
been fixed at 73° F. (22·7° C.), but for fuel
purposes in the mercantile marine the oil has
to have a flash-point of 150° F (65·5° C),
whilst for the Navy no oil flashing under
200° F. (93·3° C.) was permitted until 1913,
when the flash-point was reduced to 150° F.
On shore the flash-point allowable for a fuel
would vary with the work which is to be
done; for instance, locomotives could use
an oil having a flash-point of 73° F., provided
the climatic conditions were suitable and
should no preliminary heating of the oil be
necessary, but speaking generally, even on
land it is better to run no risk, and the flash-
point for a fuel oil should not be lower than
150 F.

A consideration of the dangers attending
the shipment of oil has led Lloyd's Registry

to formulate excellent regulations for the construction of oil ships, which may be summarised as follows :—

In addition to the usual sketches of Midship Section, profile and deck plans, sketches are to be submitted showing the arrangement of oil tanks and coffer-dams, the stiffening proposed for the transverse and longitudinal bulkheads, the construction of the tunnel and the bracket attachments at the ends of beams, stringers, webs, bulkhead stiffeners, etc.

The oil compartments are not to exceed from 24 feet to 28 feet in length.

Expansion trunks are to be fitted over the oil compartments of sufficient capacity to admit of the expansion or contraction of the oil due to changes of temperature. They are to be so arranged that the surface of the oil will not fall below the sides of the trunks when the vessel is rolling or pitching in a seaway. Where the breadth of the expansion trunk exceeds sixty per cent. of the breadth of the vessel, or the height of the trunk exceeds eight feet above the top of the oil compartments, the proposal must be specially submitted for the Committee's consideration, and, if approved, the scantlings in way of the oil compartments must be increased, and any

structural arrangements adopted as may be considered desirable.

Coffer-dams are to be fitted at the fore and after ends of the space intended for the oil cargo, and where the machinery is fitted amidships coffer-dams are also to be fitted at each end of the machinery space in order that the oil cargo may be isolated from the holds and from the engine and boiler spaces. The coffer-dams are not to be less than two frame spaces in length, and are to extend from the keel to the top of the continuous expansion trunk for the full breadth of the vessel.

The number of watertight bulkheads extending to the upper deck is to be as specified.

In vessels having the machinery aft, a poop must be fitted of sufficient length to cover the machinery space. Where the engines are fitted amidships, the bridge is to be of sufficient length to overlap the ends of the middle line bulkhead in the oil compartments.

Portland cement may be dispensed with in compartments intended for carrying oil in bulk.

Each oil compartment is to be filled separately with water and tested by pressure before the vessel is launched or while in dry

dock. The pressure is to be obtained by means of a head of water eight feet above the highest point of the expansion trunk. Cofferdams are to be tested by being filled with water to the top of the hatchway.

Electric light is to be fitted throughout on the double-wire system.

Owing to the penetrating character of the oil and the stresses to which oil vessels are subjected, due to the cargo being carried directly upon the outside plating of the vessel, it is of primary importance that the workmanship throughout be of the highest character.

Oil pumps fitted for the purpose of filling or discharging the oil compartments are to be kept entirely separate from the pumps fitted for filling or clearing the water-ballast compartments of water.

The water-ballast pipes are not to pass through the oil compartments, nor the pipes for the oil through any water-ballast spaces. A separate ballast pump is to be fitted forward of the oil compartments for the purpose of filling and clearing the forward ballast tanks.

Oil-pump rooms are to be enclosed by watertight bulkheads and have no direct communication with the machinery space.

The limber holes in the floors and inter-costals in the oil compartments are to be so arranged in the vicinity of the pumps as to admit of a sufficient flow of oil to the pump suctions.

Efficient arrangements are to be provided for clearing the tunnel and 'tween-deck spaces of water.

Sounding pipes are to be fitted in the coffer-dams.

It is of the greatest importance in oil-carrying vessels that the internal arrange-ments should be such that the compartments can be readily cleared of gas, and efficient means are to be provided for clearing the dangerous gases from the tanks by the injec-tion of steam or by the adoption of some efficient system of artificial ventilation.

Ventilators are to be fitted to the pump-rooms, coffer-dams, 'tween-decks, deck erec-tion, and other enclosed spaces, to allow of the free escape of all gases from these parts.

The tunnel is to be efficiently ventilated by large ventilators placed on the upper part of the trunks at the ends of the tunnel.

The single-wire system must not be adopted for any part of the electric lighting installa-tion in vessels carrying petroleum.

Switches and cut-outs must not be fitted in places liable to the accumulation of petroleum vapour or gas, and all lamps in places where it is possible for gas to accumulate must be made with an outer glass globe made air-tight. All wires in such places are to be lead covered, or the insulation of the cables employed is to be of such a nature as not to be affected by petroleum.

No joints of cables, switches, or cut-outs should be fitted in the pump-rooms, but the wires for each lamp therein should be carried to the lamp from a distributing-box placed outside the pump-room or companion.

When vessels classed for carrying oil in bulk are undergoing special survey, the tanks are to be cleaned out and thoroughly cleared of gas to admit of their being properly examined, and every precaution is to be taken to ensure safety during inspection.

Each oil compartment and coffer-dam is to be tested by being filled with water to the top of the hatchway in the expansion trunk or coffer-dam.

Compliance with these regulations as to construction are a necessity, as Lloyd's classification is insisted on by most port authorities, and the following regulations

for the purpose of ships carrying petroleum
through the Suez Canal, which is our great
highway for the carriage of oil from the East,
are a good example of these. The importance
of such regulations is shown by the fact that
not long ago an oil ship was burnt in the
Indian Ocean owing to the double bulkheads
specified in Clause 7 of Article 2 not being
filled properly with water, and oil or oil
vapour leaking through to the engine-room
and becoming ignited.

'Any ship laden with petroleum oil in bulk
arriving before any port of access to the Canal
must make herself known by flying at the
aftermast one of the following signals :—
By day—a red flag above one ball. By
night—a white light beneath two red
ones.

'When the ship goes through the Canal,
she must keep the above signals flying during
the whole of her transit.

'Before the ship enters the Canal, the
captain must sign and hand to the officials
of the Company one of the two declarations
herewith—

'(a) If the ship's tanks contain exclusively
petroleum oil having a flash-point not
below 23° C. (73° F.).

'(b) If the ship's tanks contain any products,
whether petroleum or by-products of
petroleum, such as gasoline, benzine,
etc., having a flash-point below 23° C.
(73° F.).

.'Moreover, the captain must strictly
attend to the due observance of the follow-
ing prohibitions during the whole of the
stay of the ship in the Canal and its
approaches :—

'All and any handling of petroleum, ben-
zine, or other substance whatsoever, having
a flash-point below 66° C. (150° F.) is abso-
lutely forbidden.

'No light with a free flame must be used.
Smoking on board the ship or carrying about
one's person any means of obtaining a light
is strictly prohibited.

'No strangers, notably electricians and
crews of the mooring boats, must be allowed
on board the ship.

'The following rules as to coaling at Port
Said must be strictly observed :—

'Coaling at night is prohibited.

'All persons engaged in coaling, all firemen
and coal trimmers, and all persons aboard,
are forbidden to use hand-lamps, or portable
lamps of any description, in the interior of

the ship, whether for purposes of working or
circulation therein.

'Lighters and coaling gangs are not allowed
alongside until coaling is about to begin, nor
must they remain there after coaling has
ceased at nightfall.

'Ships carrying petroleum oil in bulk are
also allowed to carry petroleum oil having
a flash-point not below 23° C. (73° F.) in oil-
tight containers (barrels, drums, cases).

'They are allowed to carry a complementary
cargo of petroleum oil having a flash-point
below 23° C. (73° F.) in barrels, drums, or
cases, up to 5000 cases ; that is to say,
200 cubic metres.   Such barrels, drums,
or cases must be stowed in the 'tween-
deck.

'Night transit is prohibited to ships carry-
ing petroleum oil, whether in bulk, or in
barrels, drums, or cases, of a lower flash-
point than 23° C. (73° F.).

'When the cargo consists of petroleum oil
of a lower flash-point than 23° C. (73° F.)
carried in bulk, the ship must be towed by
one of the Company's tugs during the whole
of her passage through the Canal.

'The captain of any ship having carried
petroleum oil in bulk must sign a declaration

to the effect that subsequently to the oil
cargo having been discharged all necessary
operations of washing, cleaning, or other
have been attended to, in order to avoid the
presence of petroleum oil vapour, whether
in the tanks, or in any other part of the
ship.'

In a properly constructed tank steamer
the chief danger when loaded lies in collision
or heavy straining during rough weather,
and it is during charging and discharging
the cargo that the greatest chance of accident
arises. It has long been felt that if boiler
and galley fires could be dispensed with, and
only properly installed incandescent electric
lamps used, a great step forward would
have been made towards ensuring absolute
safety.

The introduction of the Diesel engine for
marine use has given the possibility of doing
this, and tank steamers like the *Vulcanus*
are nearly perfect.

It is unnecessary to give a full description
of the Diesel engine or of the arrangements in
the *Vulcanus* here, as these points are fully
dealt with in Chapter VII.; but briefly, the
Diesel engine is an internal combustion engine
utilising heavy oil of almost any grade, which

is mixed and evaporated into air in the
cylinder, where it is fired by the high tempera-
ture obtained by compressing the mixture to
something like 500 lb. on the square inch, the
heat so produced causing its ignition, when
the expansion due to the combustion gives
the power.

It will be seen that there is no exterior
flame or spark which could ignite mixtures
of vapours and air that might find their way
into the engine-room, and there is no doubt
that this vessel represents the type of tank
steamer which will be universally adopted
in the near future.

One of the chief factors in the cost of fuel
oil is the high price of freight, but develop-
ments are now rapidly proceeding in the
direction of getting cheaper carriage, and
there is no doubt that this can be obtained
only by the introduction of Diesel-driven
tank steamers and ocean-going barges which
can be towed by Diesel-driven tugs.

In England, the chief distributing ports
to which petroleum products are brought in
bulk are Thames Haven, Bristol (Avon-
mouth), Barrow, Manchester, Liverpool, Hull,
Sunderland, Cardiff, Plymouth, and South-
ampton. Under the Conservancy regulations,

petrol is not allowed in tank steamers higher up the Thames than Thames Haven, but is discharged there and is stored in tanks, and is then put into licensed barges and brought up to London.

The barges which are at present employed for such work consist, as a rule, of ordinary barges into which tanks have been fitted; the tanks having been filled with petrol, the barges are towed by tug to the store at which they are to discharge cargo; but undoubtedly in the near future special tank barges, driven by Diesel motors instead of being towed, will be adopted.

In making such barges, however, the skin of the vessel must not be utilised as a side for the tank, as in case of collision this would be a source of danger, as a comparatively slight impact would be liable to start rivets and give rise to leakage; but with specially constructed tanks spaced away from the side of the vessel, such a danger would be reduced to a minimum.

The Thames Haven wharves and stores are unique, no other stores in the world approaching them in size. There are in all 98 tanks for the storage of petroleum, these being principally of the following dimensions :

77 feet in diameter, holding about 4000 tons
each, and 50 feet in diameter, holding about
1500 tons. The Thames Haven depot has
a river frontage of over a mile in length,
nearly two-thirds of which is at present occu-
pied by storage tanks, whilst if the demand
for petrol continues to increase at its present
rate, the whole of the available space will
in a few years be covered.

One of the special features of this great
national oil store is the beautiful arrangement
of the pipes from the tanks to the pumps
needed for discharging the cargoes of oil from
the ship to the storage tanks, or from the
tanks to the barges or barrelling and canning
departments.

Each tank has its discharge pipe and valve
close to the tank, whilst the other end of the
pipe is led into an exchange building, in which
are the pumps and other pipes leading to the
piers, etc. All these pipes terminate in flanged
openings which can be connected by flexible
pipes with any other pipe, so that the
contents of any one tank can be trans-
posed to another tank or to a pier line at
will.

The pipes from the tanks come from every
part of the system overground to the exchanges

(one exchange to each pier), and near the building are brought in perhaps a dozen abreast.

This arrangement gives absolute control over the whole storage, and allows the manipulation and general handling of the oil to be carried out with the minimum of labour and maximum of safety.

CHAPTER V

LIQUID FUELS OTHER THAN PETROLEUM

The available supply of liquid fuel from petroleum—
Cost as compared with coal—The needs of the Navy
—The sources of our present supply—Imperial
possibilities—Home supplies—Shale oil—Shale and
its characteristics—Torbane Hill mineral—Differences
between coals and shales—The Scotch shale oil
industry—The refining of crude shale oil—Yield of
shale oil and the quantity that might be made avail-
able for fuel—Dorsetshire shale—Tar and its composi-
tion—Tar oil—Drawbacks to tar oil as a fuel.

THOSE who either from want of knowledge or
from interested motives advocate the universal
adoption of oil fuel in the place of coal gener-
ally claim that it would be quite possible to
supply oil of the necessary quality at 30s.
or 35s. a ton, and that oil as a fuel is worth
twice as much as coal, so that there would
be an economy in cost as well as the enormous
conveniences of a liquid fuel for power pro-
duction. Such an idea is a mass of fallacies;
the fuel oil supply is totally inadequate;
there is no guarantee of a continuous supply;
the price of fuel oil is now £3 a ton and over,
and its value as a fuel only one and a half times

that of coal; and as the general adoption of liquid fuel must be a commercial question, it is not likely that keen business men will look at oil as a general fuel as long as this country can produce coal at anything like the present price.

For special purposes, however, the use of oil offers such advantages that the question of price hardly enters into the calculation, and it is for these purposes that for many years to come oil fuel will find its chief market.

Oil-tank steamers taking in their fuel at the oil ports at a f.o.b. price of 15s. to 20s. a ton can use it with enormous economy, but what owner would fit it in a tramp steamer in English waters when he had to pay £3 a ton for it?

The use *par excellence* for oil fuel is in the Navy, where its use gives the possibility of increased speed, increased radius of action, convenience in taking on board, and reduction in stokehold labour, and so makes it a necessity, and it will be interesting to consider in brief the question of supply of fuel oil.

The amount of coal used in this country per annum, including the Navy and Mercantile Marine, amounts in round figures to 200,000,000 tons, the surplus raised above

this being exported.   The world's output of
petroleum is only just approaching 50,000,000
tons; and of this certainly not more than
one-third would be available for fuel oil on
account of its being only the heavier frac-
tions that could comply with the requirements
as to flash-point, so that the world's
production would be less than 10 per cent.
of the total needed to replace coal.

   In the Service, in times of peace, according
to evidence published by the Committee on
Coal Supply, the consumption of coal is
about 1,000,000 tons per annum, and in
war would be far higher, so that as 1 lb.
of oil is the equivalent of 1·5 lb. of coal as
a fuel, it would be necessary to have a
guaranteed supply of an enormous quantity
of oil that could not be cut off, *i.e.* actually
in store in the country before the Admiralty
would be justified in fitting the Navy for
the combustion of oil alone as fuel.

   The fuel oil supply available in England is
very limited, as although the oil fields of
Russia, Roumania, and Galicia are worked
largely with British capital, we get but little
fuel oil from these sources; and if we did, the
closing of the Dardanelles would cut off the
supply.   At present our chief sources of

supply are the East and America; and if the Empire is to retain her supremacy on the sea, it behoves us to develop the oil fields of the Empire as rapidly as possible, in order that Canada, New Zealand, Australia, and the West Indies may aid India in supplying fuel oil for naval purposes, and add to the large quantities that will be probably available from Mexico.

In considering the price of fuel oil, it must be remembered that in America, enormous as are the supplies of oil from the Texan and Californian districts, there is the American fuel oil market to supply; and as the use of fuel oil has been developed there to a large extent, the surplus available is not great, whilst the Dutch East Indies, which supply two-thirds of the petrol used, have practically no local market for the residuum, so that although the freight would be about double that from America, it is a far more promising source of supply.

The difficulty of obtaining a steady and guaranteed supply of fuel oil from abroad leads one to seek every available source that would give us a home supply, and shale oil, distilled in large quantities in Scotland, is naturally the first to attract our attention.

As we have already seen, the Scotch shale oil industry was started by James Young in the middle of the last century, and although sadly cut into by the development of the American, and afterwards the Russian, sources of supply, it has, owing to economical working and clever engineering, succeeded in remaining a living industry in spite of the fierce attacks of petroleum combines and trusts.

The material used by Young, and known by the name of Torbane Hill mineral, was not a shale at all, but was more of the nature of a cannel coal, and is more generally known by the name of Boghead cannel, being of the same character as the celebrated New South Wales cannel. These cannels are the petrified remains of the resinous constituents of the seed cells of a moss of the same family as that from which we now obtain lycopodium, and the fallen seeds having been drifted down in enormous quantities by streams, have collected and formed small areas, often of considerable thickness, of 'cannel coal.'

This material, when distilled, yielded as much as 125 gallons of oil per ton; but the deposit having become exhausted in 1862, the shales of Linlithgow and Midlothian have since then furnished the bulk of the oil.

A shale differs from a coal in that when heated to redness out of contact with air, the shale yields volatile matter and leaves behind a residue of mineral matter, whilst a coal yields volatile matter and leaves the residue of carbon, which we call 'coke.'

The mineral matter left by shale may be anything from 70 to 80 per cent., and the amount of oil obtainable from this class of bodies varies over a wide range, the good shales yielding 30 to 60 gallons per ton, whilst the inferior shales give only about 18. But there is the saving clause in favour of poor shales, that they give 70 to 80 lb. per ton of ammonium sulphate, whilst the richer varieties yield only 25 to 35 lb. of this compound, which from its high value as a fertiliser goes far towards making up for the deficiency in oil. These shales are found in the Calciferous sandstone lying between the Carboniferous limestone and the old Red sandstone, and there are about eight principal seams varying from two to sixteen feet in thickness, the upper seams being generally richest in oil and the lower richest in ammonium sulphate. Shales of the same nature occur in many other parts of the

world, and at one time shale oil was a flourish-
ing industry in France.

In the early days of the industry the shale
was distilled in horizontal retorts in much the
same way as coal; but the advantages of the
vertical retort for getting rid of the mineral
ash by gravity and in many other ways soon
led to its adoption, and the introduction of
steam into the distilling mass and the improve-
ments due to Young, Fyfe, Henderson, and
Beilby have made the process a model indus-
trial operation in which every by-product of
any value is recovered.

The crude shale oil condensed from the
still has a dark greenish colour and a specific
gravity of about 0·860 to 0·890, and it differs
from crude petroleum in containing in addition
to the ordinary petroleum hydrocarbons,
olefines, pyridines, and small quantities of
cresol and phenol, together with a much
larger proportion of paraffin wax than is
found in any native crude oil, which, separat-
ing in crystals as the oil cools, often makes it
very thick and gives it a tendency to set.
Shale oil may, in fact, be looked upon as
intermediate between natural oil and tar,
the constituents of the natural oil having
been formed by a very low heat continued

over long ages, whilst the shale oil has been
produced by a dull red heat acting for a short
period.

The crude oil undergoes a distillation in
a continuous still, and the result, known as
'once run oil,' is then kept at a temperature
at which the paraffin will not separate, by
means of a steam coil, and is agitated with
acid and alkali, after which the oil is frac·
tionated by distillation into crude naphtha
and burning oil, the heavier oils and paraffin
wax forming the residue which sets solid on
cooling, and is often redistilled.   In these
distillations steam is generally employed,
and is blown through the heated liquid after
the more volatile portion has been distilled
off.   These fractions are again treated with
sulphuric acid and soda before they can be
obtained in a marketable condition, and often
again distilled, whilst the paraffin wax has
to be recovered from the residual portion
by getting rid of as much oil as possible and
dissolving out by naphtha and recrystallising
or sweating it out by carefully regulated
heat, after which it has to be fused and
decolourised by animal charcoal.

The normal yield from crude shale oil
after refining approximates to :—

Naphtha	.	.	.	.	4 per cent.
Burning oils	.	.	.	.	33 ,,
Intermediate and heavy oil			.		25 ,,
Paraffin .	.	.	.	.	10 ,,
Loss	.	.	.	.	28 ,,

The output of crude oil which could at present be made may be taken at 50,000,000 gallons, and this would mean roughly 200,000 tons; so that if 25 per cent. could be used as fuel oil, this would amount to 50,000 tons, which being distilled close to the new naval base at Rosyth, would form an important addition to the liquid fuel supply.

It seems possible that some arrangement might be come to between the shale oil companies and the Government by which a sufficiently large quantity of fuel oil might be obtained to make the situation far safer.

Shale deposits also occur in the South of England, in Dorsetshire, near Kimmeridge, from which they take the name of Kimmeridge shales. These shales yield as much as 50 gallons of oil per ton; but unfortunately they are so highly sulphurised as to be useless, the sulphur being held in a form that defies the ordinary methods of purification; if it were not so, we should have another source of fuel supply close to the Portland base, which would be invaluable.

Turning from this highly promising source of native supply, the next possible one is coal tar, which on distillation yields tar oil.

Commercial tar, as obtained at the ordinary gas-works from the carbonisation of bituminous coal, is a black viscous liquid, having a specific gravity ranging from 1·1 to 1·2, according to its origin. The tar made from coal *per se*, or with only a small percentage of cannel, is usually heavier than that derived from the carbonisation of coal containing larger proportions of cannel, as the quantity of light oils yielded by the cannel reduces the specific gravity of the product. The following analysis represents the average ultimate composition of a coal tar made from a bituminous coal :—

Carbon	77·53
Hydrogen	6·33
Nitrogen	1·03
Sulphur	0·61
Oxygen	14·50
	100·00

Tar is an exceedingly complex mixture of various compounds of the above elements : traces of about 140 bodies have been identified; but for all practical purposes the compounds given in the following table may be regarded as the chief constituents :—

	Neutral Hydrocarbons.	Boiling Point. °C.	Formulæ.	Specific Gravity
Liquid	Benzene .	80	C_6H_6	0·88
	Toluene .	110	C_7H_8	0·87
	Xylene .	142	C_8H_{10}	0·87
	Isocumene .	170 .	C_9H_{12}	0·85
Solid	Naphthalene	217	$C_{10}H_8$	..
	Anthracene	360	$C_{14}H_{10}$	..
	Chrysene .	..	$C_{18}H_{12}$	..
	Pyrene .	..	$C_{16}H_{10}$	..
Alkaline Products	Ammonia .	..	NH_3	..
	Anilin .	182·5	C_6H_7N	1·02
	Picoline .	130	C_6H_7N	0·96
	Quinoline .	239	C_9H_7N	1·08
	Pyridine .	117	C_5H_5N	..
Acids	Carbolic acid	180	C_6H_6O	1·07
	Cresylic acid	..	C_7H_8O	..
	Rosolic acid	..	$C_{19}H_{14}O_2$	..
	Brunolic acid	..		..
	Acetic acid	118	$C_2H_4O_2$	1·06
	Free carbon	..	..	..

Tar in its crude condition contains so much solid carbon and leaves so much residual pitch that it can be used as a fuel only with very unsatisfactory furnace arrangements.

Even in the above list many of the compounds occur in coal tar in comparatively small quantities, and it is possible to simplify one's views of the composition of tar still further, and to regard it as being composed of a mixture of benzene, naphtha, naphthalene, carbolic acid, and pitch, these bodies being

taken as representing the various classes of fractions into which the tar can be distilled.

When a sample of tar is distilled, the light oils are the first to come over, consisting mainly of benzene, but containing a certain proportion of similar compounds, such as xylene and toluene ; then follows the heavy tar oil, the fraction from which carbolic acid and kindred bodies are extracted; and, finally, pitch is left, which, if the distillation be stopped at this stage, would be of a soft character, but if the residue be subjected to further distillation, anthracene oils come over, and the pitch that remains is of a much harder nature.

The heavy tar oil, or 'creosote oil,' forms a fairly good liquid fuel. The specific gravity is usually in the neighbourhood of 1·1, hence its name of 'heavy oil,' being heavier than water; it also contains large quantities of carbolic and cresylic compounds and derivatives, as well as much naphthalene, which latter substance when purified is used for the albo-carbon lamps, disinfecting purposes, etc.

Another variety of oil is obtained from blast furnaces, and is known as blast-furnace oil, or 'phenoloid oil,' but although it can be used as a liquid fuel, yet neither the phenoloid nor the creosote oils can be obtained in

sufficient quantities to make them an im-
portant element as a source of liquid fuel.
Moreover, both these oils give off fumes of
a very pungent character when undergoing
combustion, so that when used in a closed
stokehold they give rise to smarting of the
eyes, which is a great drawback to their use
for marine purposes.

In Germany, where there is a heavy import
tax upon oil, the use of tar and tar oils in
the Diesel engine has attracted considerable
attention, and for the last ten years tar and
creosote oils have been satisfactorily used. As
the same difficulties will probably be found in
this country when attempts come to be made
to employ these fuels, it will be as well to
review briefly the troubles that arose, and
the way in which they were surmounted.

The pipes and nozzles of the burners were
found to become choked with muddy deposits
of solid hydrocarbons, consisting mainly of
naphthalenes, which formed a crust also at
the mouths of the burners. These deposits
made the working of the feed-pumps difficult,
and the solid hydrocarbons and low percentage
of hydrogen in the oil increased the tempera-
ture of ignition.

The crude tar oils varied in composition

and quality with differences in the temperature of carbonisation, even when the same coal had been used, which necessitated constant alteration in the feed and air adjustments of the engine. Of recent years, however, improved methods of fractionation and refining the tar oil, together with careful selection of the material, have ensured a supply of fuel of constant and regular quality, without the drawbacks incidental to the use of crude tar oils.

The German specification for tar oil for Diesel engines is:—

1. Tar oils should not contain more than a trace of constituents insoluble in xylol. The test on this is performed as follows: 25 grammes (0·88 oz. avoir.) are mixed with 25 c.c. (1·525 cub. in.) of xylol, shaken and filtered. The filter paper before being used is dried and weighed, and after filtration has taken place is thoroughly washed with hot xylol. After re-drying, the weight should not be increased by more than 0·1 gramme.

2. The water content should not exceed 1 per cent. The testing of the water content is made by the well-known xylol method.

3. The residue of the coke should not exceed 3 per cent.

4. When performing the boiling analysis, at least 60 per cent. by volume of the oil should be distilled on heating up to 300° C. The boiling and analysis should be carried out according to the rules laid down by the Trust.

5. The minimum calorific power must not be less than 8800 cal. per kg. For oils of less calorific power, the purchaser has the right of deducting 2 per cent. of the net price of the delivered oil for each 100 cal. below this minimum.

6. The flash-point, as determined in an open crucible by Von Holde's method for lubricating oils, must not be below 56° C.

7. The oil must be quite fluid at 15° C. The purchaser has not the right to reject oils on the ground that emulsions appear after five minutes' stirring when the oil is cooled to 8°. Purchasers should be urged to fit their oil-storing tanks and oil pipes with warming arrangements, to redissolve emulsions caused by the temperature falling below 15° C.

8. If emulsions have been caused by the cooling of the oils in the tank during transport, the purchaser must redissolve them by means of this apparatus. Insoluble residues

may be deducted from the weight of oil supplied.

It has been found that the tar from horizontal and inclined retorts in which light charges and high temperatures have been used yields tar oil which is useless in the Diesel engine; but when its source is the vertical retort, the blast furnace, or coke oven tar, it can be perfectly well used by employing 5 per cent. of heavy petroleum to act as an ignition oil.

Vegetable and animal oils are not suited for liquid fuel purposes, as, apart from their cost, many of them have the property of oxidising to resinous compounds, which, although of little importance when the oil is burnt in a boiler, would in an internal combustion engine choke and cause the valves to stick, whilst the presence in them of combined oxygen lowers their thermal value. Some kinds, however, can be made to do fairly well in the Diesel engine, and experiments on their application are now being made in Germany.

CHAPTER VI

LIQUID FUEL AND ITS COMBUSTION

The advantages of liquid fuel for marine use—The early
attempts to use petroleum as a fuel—Nobel's troughs
—Systems depending on the gasification of oil before
combustion, and the cause of their failure—The
spraying or atomising of oil—Steam injector burners
—Aydon's burner—The Holden burner—Rushden
and Eeles—Orde—Objections to steam injection for
service purposes—Pressure burners—The Körting,
Swensson, and Kermode burners—Air-pressure
burners—The fitting of liquid fuel installations—
Arrangement of furnaces—Necessary precautions
—Specification of oils for liquid fuel—The advan-
tages of steam injection with ample combustion
space—The cause of smoke—The value of liquid
fuel as compared with coal—Oil as an auxiliary to
coal—The arrangements for burning oil with coal
—Lloyd's regulations for the storage and use of
liquid fuel—American views on liquid fuel—Com-
parison of the evaporative power of the oils which
can be used as liquid fuel—Calorific value—The calcu-
lation of calorific value—Calculations of evaporative
value—Direct determination of calorific value—
Calorimeters—The Mahler bomb.

THE advantages of liquid fuel in the Navy of
any nation are so great and are now so fully
recognised that it is unnecessary to recapitu-
late them at any length. Oil fuel has one and
a half times the efficiency of Welsh steam coal,
so that, weight for weight carried, the radius

of action is extended 50 per cent. Oil fuel can be pumped on board from a tender whilst a ship is travelling at a considerable speed and under most conditions of sea. The stowage space of a ton of oil is 38 cubic feet, whilst a ton of Welsh coal occupies 43 cubic feet. With coal the bunkers must be above the level of the stokehold; with oil, it can be stored in the double bottoms. With oil, only one-third the number of stokers is required that is needed with coal. With oil fuel, steam can be maintained as long as the fuel lasts; with coal, cleaning fires, clinkering, and other factors limit the period. With oil, rapid raising of steam in an emergency presents no difficulties; and, finally, whereas coaling is one of the greatest trials on board ship, filling the oil bunkers is done by gravity and without labour or dirt.

It has taken nearly fifty years to bring oil fuel combustion to the pitch of perfection it has now attained, and the early attempts and failures, made mostly by private individuals, are full of valuable lessons.

The earliest attempts to utilise oil for steam-raising resulted in a very poor efficiency, and the first successful method of burning the oil on land was the system known as 'Nobel's

troughs,' which consisted of open troughs
placed one above the other at the mouth
of the furnace in such a way that the oil
fed into the top trough overflowed into the
second, and so throughout the series, the
flame of the burning oil being drawn by the
chimney draught, together with the air
needed for the combustion into a mixing
chamber, and afterwards through the furnace
tubes and flues.

Although this system gave very good
results with crude oil, the method was not
suitable for oils of the high specific gravity
and flash-point now used as fuel; and in 1863
the plan arose of using the oil either gasified
by heat or in the form of a very finely divided
or, as it is termed, 'atomised' spray. The
former method was first introduced by Colonel
Foote, of the United States, who fitted a gun-
boat with his apparatus, with the result that
the speed was nearly doubled, whilst the
stokehold staff was greatly reduced. The
oil passed by gravity into a retort placed
a short distance within the furnace, and was
gasified there, and the oil gas was burnt at
burners at the furnace mouth, after being
diluted with hydrogen formed by passing
steam over heated iron filings, whilst air

from a force-pump was fed into the flame to
perfect the combustion. The process, how-
ever, was a failure, as the oil retort and
burners choked with carbon, and the iron
for making the hydrogen had to be renewed
each time.

Similar systems of gasifying the oil were
introduced by Simms and Barff, and later by
Eames and Durr; but in all these methods
considerable trouble was found with the
retorts, which had a very short life, and
with choking of the burners. Moreover, it
was evident that the apparatus used for the
burning of the liquid fuel must be self-
contained and of the simplest character, and
that external sources of heat and auxiliary
apparatus could not be employed.

At the present time the process almost
universally adopted is to spray the oil directly
into the furnace in a state of division so fine
as to be almost a mist; and this may be done
by ejecting the oil from a suitable jet by a
steam blast, or by using the oil under con-
siderable pressure, so causing it to escape as
a spray through minute orifices; whilst a
third method, which, however, is seldom used
afloat, is to employ compressed air in the
same way as steam for injection. Nearly all

the burners first devised were upon the
principle of steam spraying, and in ships of
the mercantile marine and for locomotive
work many of them proved highly successful.

Mr Holden, of the Great Eastern Railway,
who was one of the pioneers in the use of
liquid fuel, devised a burner for locomotive
use on the principle of steam injection,
which proved very successful, and is largely
employed. The method of using it is to first
raise steam by a coal fire in the locomotive
boiler until a head of 30 or 40 lb. of steam
is obtained; the fire is then raked level,
covered with firebrick, and a few pieces of
oily waste lighted and thrown into the
furnace, and the liquid fuel injector is started.
The combustion is smoky at first, but as
the temperature rises the steam ring jet is
turned on and sucks in enough air to complete
the combustion, and smoking ceases.

In Messrs Aydon, Wise and Field's burner
the oil flows to the injector by gravity and
is driven out by a steam jet, the issuing mix-
ture of steam and oil being made to draw air
in around the jet to aid in the combustion.
The Holden burner, though originally designed
for locomotives, is also arranged for marine
work; and other burners have been devised,

depending upon the atomising of the oil by
steam, and differing mainly in their mechanical
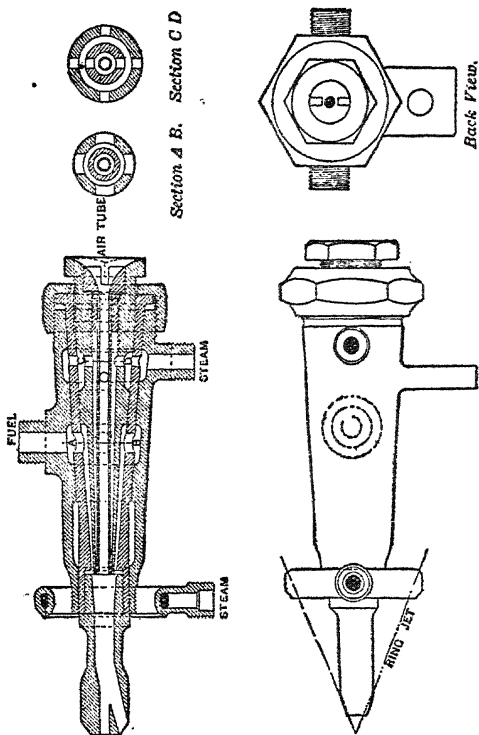
HOLDEN INJECTOR (Locomotive).

arrangements ; amongst these may be men-
tioned the burners of Rushden and Eeles, and
Orde.
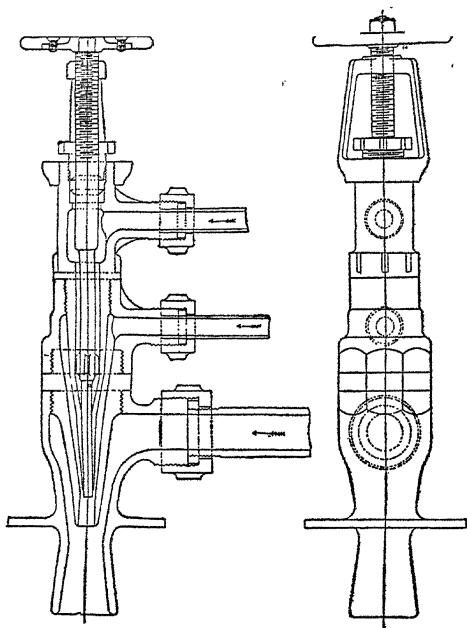
ORDE BURNER.

When, however, burners on this principle
came to be tried in the Service, two objections
presented themselves : in the first place,

they needed steam, and all the available
steam was required for the engines; and
in the second place, they failed to burn the
requisite amount of oil without smoke under
the conditions of combustion space available,
although they answered perfectly when used
under boilers with much more room in which
to complete combustion.
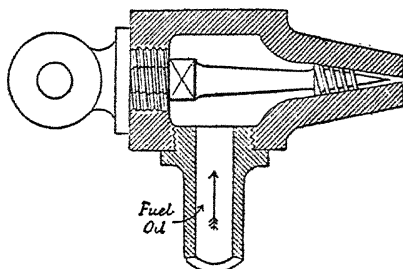
KÖRTING'S INJECTOR.

The second class of oil burners comprises
those in which the oil under pressure pulverises
itself in its escape. One of the most successful
of the early forms of burners on this principle
was that devised by Körting, in which heated
oil is forced under a pressure of 50 lb. on the
square inch through the nozzle of an injector.
In the jet is a spindle on which is a spiral
screw, so that the oil, as it travels along the

jet, is given a centrifugal motion, which
materially assists in the atomisation and
spraying of the oil. In the Swensson burner
the oil is forced from the jet on to the point
of a sharp-edged metal cutter, which serves
the same purpose of disintegrating the oil
into a fine spray.

Another, and certainly the most successful
of this class of burner, is the Kermode, in
which the swirling motion given to the oil
spray in the Körting burner is attained by
causing the oil to escape under pressure
through three small channels arranged in the
face of the jet in such a way that a cone of
swirling mist having its apex at the burner
is formed, thus delaying the rush of the oil
mist through the furnace and causing better
admixture with the air supply, in this way
giving time to complete the combustion.

The liquid fuel enters the burner under
pressure through A, passes round the chamber
I, and down between the outer and inner
walls of the burner, B, D. The inner cylinder
B abuts upon the cap E, and on the end of
B are cut grooves H, which are tangential to
the cone end of the spindle C, which serves
to contract or enlarge the opening through
the cap nut E. The oil forced through the

tangential grooves is deflected by the conical surface of the spindle and through the opening in the cap.
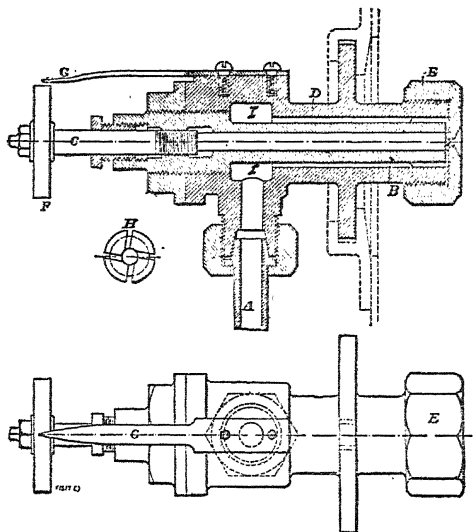
KERMODE PRESSURE JET BURNER.

These burners, used with forced or induced draught, give excellent results, and are a great advance upon the old types of burner, in which the atomised oil was hurried forward through the combustion space so rapidly

that incomplete combustion and smoke resulted.

The burner used in the Service is on the oil-pressure system, in order to avoid the necessity for extra boilers to provide steam and the using for this purpose of fresh water.

In fitting an oil-fuel installation for marine work, the oil is usually first pumped from the tank through a filter of fine wire gauze, from which it passes through a steam heater, consisting of a nest of tubes through which the oil flows, whilst the exterior of the tubes is heated in a casing through which exhaust steam passes, raising the oil to 150–180° F. If the oil has a flash-point of 150° F., the temperature should not be raised above that, as any vapour generating might cause a break in the oil column and extinguish the burner. A second hot-oil filter is often fitted between the heater and the burners. The burner or burners are fitted into the furnace front, and the necessary air for combustion is admitted to each spray jet through separate automatically closing air tubes projecting in front of the nozzle of the burner.

When oil alone is used as a fuel, the fire-bars are removed, and the whole of the interior of the furnace lined with firebrick,

which not only protects the plates, but when once heated holds the heat and prevents chilling of the flame.

The third method of spraying or atomising oil is by compressed air, which is not so much used for marine purposes, but is largely employed ashore, where an intensely hot flame is needed for furnace purposes. The most successful form of air injection burner is also
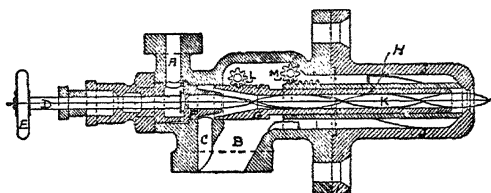
KERMODE AIR INJECTION BURNER.

due to Kermode, and can also be adjusted to the use of steam.

In the burner shown above the oil enters at the branch A, and its flow is regulated by the conical valve operated by the hand-wheel E. The air, which has been heated previously by passing through a suitable heater placed in the flues or uptakes of the boiler, enters at B and C, the air passing through C meeting the oil flowing past the

conical valve, and the oil and air then travel
together to the burner mouth, the oil being
vaporised rapidly on the way. To facilitate
the vapourisation and to ensure the complete
admixture of the air and oil vapour, the
central tube is fitted with a helix K. The
air supply can be regulated at two points
by means of hand-wheels, racks, and pinions;
the pinion L regulates the air supply to the
oil-delivering nozzle at the conical valve F,
whilst the second pinion at M operates the
outer sliding tube, by means of which the
amount of air escaping round the mixed jet
at the mouth of the burner can be varied.
The air pressure required varies with the
combustion space available from half a pound
to four pounds.

From a theoretical point of view, air injec-
tion would be far superior to steam injection,
as a considerable proportion of the air needed
for the combustion is supplied mixed with the
atomised oil, the flame is shortened and great
intensity attained; whilst steam injection
retards initial combustion by dilution, and
necessitates a much longer travel of the flame
before sufficient oxygen can be obtained from
the air to complete combustion, thus lengthen-
ing the flame. Moreover, the steam in its

chemical reactions with the hydrocarbons takes up heat, so that at first sight air injection has many advantages. In practice, however, the necessity of air compressors renders imperative not only the use of auxiliary apparatus, but with some burners the consumption of steam for the compressor is greater than would be employed with direct steam injection, this at once condemning them for Service purposes. The length of flame also, the shortening of which by air injection was one of its greatest advantages, became unnecessary when 'swirling' pressure injectors were introduced, whereby the spray was given a rotary travel, and proper mixing and slow travel were ensured.

Most of the early air injectors needed the air to be under a pressure of 30 to 50 lb. per square inch to give the best results; but low-pressure air burners working with one-tenth this pressure are now made which show very good performances.

Where air-pressure injectors are used for steam raising, greater precautions have to be taken in lining the furnace with firebrick and preventing the direct impact of the flame on any unprotected surface, as the injector is, in fact, a blast blowpipe, and the best firebrick

would be rapidly fused if exposed to its direct action. One great advantage of the air burner is that with proper arrangements inferior forms of liquid fuel, such as the tar from coke ovens, blast furnaces, and gasworks, can be used, but under these conditions the air should be heated to a fairly high temperature.

In tank steamers fitted for liquid fuel all sorts of furnace arrangements have been tried, but in most the oil spray from the injector is directed on to a baffle of firebrick, which serves the purpose of breaking up the spray still further, and, when hot, of keeping it ignited; and also the firebrick serves to protect the plates of the furnace from the direct impact of the flame.

Opinions still differ as to whether the burning oil should be provided with enough air to produce an almost non-luminous combustion, or whether the oil should give a highly luminous flame at first, with complete combustion by an additional supply of air when the combustion chamber is reached.

In an ordinary furnace burning coal, radiation from the incandescent fuel plays a most important part in the transmission of heat to the water, and this transmission of

heat is but small with a non-luminous flame, so that the radiating effect has to be obtained by raising the firebrick baffle and furnace lining to a high temperature. The incandescent particles in a luminous flame, however, give a considerable amount of radiation effect; but imperfect combustion has to be carefully guarded against, and a secondary hot air supply provided at the furnace bridge, otherwise choking of the boiler tubes and the emission of dense black smoke are amongst the troubles that follow.

Certain precautions have to be taken in the burning of oil through injectors. All solid matters must be allowed to settle out, in order to avoid any risk of choking the jet, and all water must be removed, as it has been found that the presence of water in the oil may cause the flame to be extinguished at the jet, when the oil gas or oil spray and air would form an explosive mixture in the furnace, which might have disastrous results.

To ensure the separation of the solid matter and the water from the oil, the latter is heated in the store tank by a steam coil, and as oil expands on heating more rapidly than water, this has the effect of decreasing the density of the oil, and consequently the separation

takes place far more quickly. Two settling tanks are generally employed, the oil being used from the one whilst it is settling in the other. The water can be drawn off through a tap in the bottom of the tank, whilst the oil is pumped through filters of wire gauze of very fine mesh to eliminate all suspended particles.

The oils often employed for fuel purposes are so thick and viscid that they require heating before they will flow with sufficient freedom through the pipes to the burner, but a good fuel oil should be fluid enough to flow through a half-inch pipe even at very low temperatures.

Several factors besides that of viscosity must be taken into consideration in the choice of a fuel oil. The sulphur present in the oil must be reduced to a minimum by purification, otherwise the action of the sulphur on the copper and copper alloys of the injectors and fittings would cause their rapid corrosion and destruction. The oil, in fact, should not contain more than 0·75 to 1 per cent. of sulphur.

All foreign matter should be removed from the oil by decantation and filtration, and more especially should all water be separated.

A safe allowance to make for the amount of air supply to obtain smokeless combustion is 24 lb. of air per lb. of oil.

The specification of a fuel oil for Admiralty use is:—

'The oil fuel supplied shall consist of liquid hydrocarbons, and may be either—

'(a) Shale oil; or

'(b) Petroleum, as may be required; or

'(c) A distillate or a residual product of petroleum,

and shall comply with the Admiralty requirements as regards flash-point, fluidity at low temperatures, percentage of sulphur, presence of water, acidity, and freedom from impurities. The flash-point shall not be lower than 200° F., close test (Abel or Pensky-Martens).[1]

'The proportion of sulphur contained in the oil shall not exceed 0·75 per cent.

'The oil fuel supplied shall be as free as possible from acid, and in any case the quantity of acid must not exceed 0·05 per cent., calculated as oleic acid when tested by shaking up the oil with distilled water, and determining by titration with decinormal alkali the amount of acid extracted by the water, methyl orange being used as indicator.

[1] In some cases it is now reduced to 150° F.

'The quantity of water delivered with the oil shall not exceed 0·5 per cent.

'The viscosity of the oil supplied shall not exceed 1000 seconds for an outflow of 50 cubic centimetres at a temperature of 32° F., as determined by Sir Boverton Redwood's Standard Viscometer (Admiralty type for testing oil fuel).

'The oil supplied shall be free from earthy, carbonaceous, or fibrous matter, or other impurities which are likely to choke the burners.

'The oil shall, if required by the Inspecting Officer, be strained by being pumped on discharge from the tanks, or tank steamer, through filters of wire gauze having 16 meshes to the inch. The quality and kind of oil supplied shall be fully described. The original source from which the oil has been obtained shall be stated in detail, as well as the treatment to which it has been subjected, and the place at which it has been treated.

'The ratio which the oil supplied bears to the original crude oil should also be stated as a percentage.'

As before stated, there are three methods employed for the pulverisation of the oil— pressure, steam, and air injection. Each of

these processes has its advantages and drawbacks, and local conditions will probably influence to a large extent the selection for particular requirements.

When steam is employed, an extra strain is thrown on the boilers, as 0·2 lb. of steam is required per I.H.P. hour, and this would generally entail extra boilers; but, on the other hand, the presence of steam aids in the combustion not merely by mechanically diluting the gas, but by chemical interaction and decomposition produces a mixture which is comparatively easy to burn. If a hydrocarbon be heated to a sufficient temperature with excess of steam, the gases carbon monoxide and hydrogen are formed; but in practice, the amount of steam necessary to obtain this complete decomposition is never attained, and the result is that the oil breaks down into hydrocarbons of comparatively simple molecular structure diluted by hydrogen and carbon monoxide, which can be burnt without much trouble and with freedom from smoking, if the combustion space is sufficient.

The belief that the presence of the hydrogen and carbon monoxide adds considerably to the heating effect is, of course, an error, as it takes just as much heat to decompose the

steam as is yielded by the combustion of the products, so that it makes no difference in the balance of heat whether pressure or steam be used for the combustion of the oil, and any increase in heating effect found with steam is due merely to the increased facilities it affords for the complete combustion of the oil.

In the pressure injector the oil issues from the nozzle in an inverted cone and in a condition of such fine division as to be akin to a vapour. If the burner be fitted in the open air and this spray be lighted, the first few feet burn with a bright and intensely hot flame; but further on, the cooling influence of the outer air begins to take effect, and black smoke appears. As the cooling action increases so the formation of black smoke gets more pronounced, and the final result is dense clouds of smoke mingled with a bluish-white smoke from the unburnt oil vapour and oil gas.

In a furnace the air supply being drawn mainly from the front is heated to a considerable degree before it is required for the combustion, so that the point of incomplete combustion is removed further from the furnace mouth, and the combustion area is

also lengthened by the draught of the chimney, so that probably the formation of smoke does not take place until the combustion chamber is reached. When once the carbon particles have been formed and cooled, it is a very difficult matter to burn them up again with air; but steam acts on the finely-divided carbon with great rapidity, provided the temperature be in the neighbourhood of 1000° C. It is evident that cooling of the flame before combustion is complete is one cause of the formation of smoke, and in order to render the combustion complete, cold air in large quantities has sometimes been admitted; but this has proved to be an even worse mistake than too little air, as the exterior of the flame gets cooled, the evaporative power of the fuel is seriously reduced, and heavy smoke formed.

Varying conditions of use cause differences in the results obtained with liquid fuel, but a ratio of 3 to 2 seems to be a fair average comparison between coal and oil for steaming at sea, and some vessels give even better results than this.

In the Service vessels of all nations the conditions are quite different from those in the merchant service. An important factor

in the use of oil fuel is that plenty of com-
bustion space is a necessity, as a large amount
of air is required for the combustion of the
oil gas or spray, whereas with coal the largest
proportion of the combustion takes place on
the fire grate. This space is readily obtainable
in a merchant ship, and the average com-
bustion of $2\frac{1}{2}$ lb. of oil per cubic foot of
combustion space will give full steaming power.
In the Navy, however, the space available is
less, and a far larger quantity of oil would
have to be consumed per cubic foot of com-
bustion space in order to obtain the desired
result.

Even with coal this problem of combustion
area and air supply is a very important one.
Given good Welsh steam coal, the amount of
smoke emitted is very little; but using a
bituminous coal, a large volume of smoke
would be seen issuing from the funnels,
showing that the combustion area and air
supply were inadequate to ensure proper
combustion. When, however, oil comes to
be used, the volume of gas yielded is about
double that given off by the same weight of
coal, and as it is a gas far richer in hydro-
carbons, the volume of air required for its
proper combustion will be much greater, so

that the use of oil fuel necessitates considerable alteration in the usual furnace arrangements as regards draught.

The amount of liquid fuel available for Service purposes is far too limited to allow of its being employed *per se*, and it is now fitted as an auxiliary to coal for use in the larger vessels, although smaller craft, such as destroyers, are arranged for burning liquid fuel only. At the present day all the newer battleships and cruisers are fitted to burn either coal or a mixture of coal and oil (the only exception being in the new type of American Dreadnoughts, which are fitted for oil only), and although this method of using the oil is not the best—it being evident that a furnace which will suit the combustion of coal will give less complete combustion with a dense flame of oil burning above the coal— yet the results obtained justify its adoption.

In order to do this the oil burners are generally fitted in position with special air supplies that can be shut off when burning coal alone ; the furnace arrangements are otherwise unchanged, and when the fire is in good condition the oil burners are started and air admitted only above the fire. Under these conditions the fire will not need cleaning,

but if the oil burning extends over twenty-four hours it will be necessary to thin the fires by removing clinker and ash at intervals.

When burning coal and oil together, generally about 25 to 30 per cent. of the fuel burnt is oil, and with these proportions very good results can be attained.

For the mercantile marine, Lloyd's regulations as to the conditions for the storage and use of liquid fuel are as follows :—

'In vessels fitted for burning liquid fuel, the compartments for carrying oil fuel must be strengthened to efficiently withstand the pressure of the oil when only partly filled and in a seaway. They must be tested by a head of water extending to the highest point of the filling pipes, or 12 feet above the load-line, or 12 feet above the highest point of the compartment, whichever of these is the greatest.

'If peak tanks or other deep tanks are used for carrying liquid fuel, the riveting of these should be as required in the case of vessels carrying petroleum in bulk.

'Each compartment must be fitted with an air pipe, to be always open, discharging above the upper deck.

'Efficient means must be provided by wells and sparring, or lining, to prevent any leakage from any of the oil compartments from coming in contact with cargo or into the ordinary engine-room bilges. If double bottoms under holds are used for carrying liquid fuel, the ceiling must be laid on transverse battens, leaving at least two inches air-space between the ceiling and tank top, and permitting free drainage from the tank top into the limbers.

'The pumping arrangements of the oil fuel compartments must be absolutely distinct from those of other parts of the vessel. If it is intended to sometimes carry oil and sometimes water ballast in the various compartments of the double bottom, the valves controlling the connections between these compartments and the ballast donkey-pump, and also those controlling the suctions of the special oil pump, must be so arranged that the suctions for each separate compartment cannot be connected at the same time to both pumps. No wood fittings or bearers are to be fitted in the stokehold spaces. Where oil-fuel compartments are at the sides of, or above, or below, the boilers, special insulation is to be fitted where necessary to protect

them from the heat from the boilers, their
smoke-boxes, casings, etc.

'If the fuel is sprayed by steam, means are
to be provided to make up for the fresh water
used for this purpose.

'If the oil fuel is heated by a steam coil
the condensed water should not be taken
directly to the condensers, but should be led
into a tank or open funnel mouth, and thence
to the hot well or feed tank.

'The above arrangements are applicable
only to the case of oil fuel, the flash-point of
which as determined by Abel's close test does
not fall below 150° F.'

A series of experiments on the use of liquid
fuel was carried out by the United States
Navy, and the conclusions arrived at may be
stated shortly :—

'The oil can be burned in a very uniform
manner.

'The evaporative efficiency of every kind
of oil is about the same.

'The marine boiler can be forced to as
high a degree with oil as with coal.

'No ill effects to the boiler have been noticed
up to the present.

'The firemen are disposed to favour
oil.

'The air for combustion should be heated if possible before entering the furnace.

'The oil should be heated to promote atomisation.

'Higher pressures are more advantageous than lower when using steam for the atomising of the oil.

'Under heavy forced draught conditions it has not yet been found possible to prevent smoke issuing from the funnels, in spite of special efforts being made to secure complete combustion. (This question has now been solved by improved burners.)

'The consumption of liquid fuel cannot be forced to so great an extent when steam is used as the atomising agent, as when compressed air is used for this purpose.

'The efficiency of the plant will depend upon the general character of the installation of fittings, etc., so that only experienced firms should be entrusted with the work. The form of burner plays but a small part in the success of liquid fuel, but the method of installation counts for much.'

Liquid fuel has been tried for locomotives, and various grades of oil tar have been experimented with. The results have been most successful, and a number of locomotives

all over the world are now equipped for using
liquid fuel, but the question of cost is the
all-important one.   Where, however, oil can
be obtained at a cheap rate, as in Mexico
and on the American, Russian, and Austrian
railways, oil fuel is the chief agent employed.

The following table gives the calorific and
evaporative values of various liquid fuels, and
with the exception of the blast furnace and
heavy tar oils it will be seen that there is not
such a great difference in their calorific values.
The results were obtained in practice under
the same boiler :—

	Specific Gravity.	Flash-Point. ° F.	Calorific Value by Bomb.		Actual Evaporative Power in practice from and at 212° F.
			Calories.	B.Th.U.	
American residuum . .	·886	350	10,904	19,627	15·0
Russian ostatki	·956	308	10,800	19,440.	14·8
Texas . . .	·945	244	10,700	19,242	14·79
Burma . . .	·920	230	10,480	18,864	14·5
Barbadoes . .	·958	210	9,899	17,718	14·2
Borneo . . .	·936	285	10,461	18,831	14·0
Shale oil . .	·875	288	10,120	18,217	13·8
Blast furnace oil	·979	206	8,933	16,080	12·0
Heavy tar oil .	1·084	218	8,916	16,050	12·0

With coal the best results would have been
between 9 and 10 lb. of water from and at
212° F., when used in the same boiler.

It is claimed that the evaporative values
given above have many times been exceeded,

and it is said that as high as 18·95 lb. of water have been evaporated per pound of oil fuel; but for long periods of steaming it seems improbable that 15 lb. would be much exceeded, although doubtless for short periods careful nursing might give a slightly higher figure.

In places where liquid fuel is cheap and abundant it is used for smelting ores and similar work, whilst in particular cases, such as for riveting machines, special furnaces, etc., liquid fuel is a most convenient source of heat, on account of its ease of application and the high temperature obtainable by its use.

It is also being used for glass making, biscuit baking, cement and steel manufacture, and welding.

The latest ideas on the combustion of oil are based on what is known as 'flameless combustion.' When a stream of gas or combustible vapour issues from a jet the exterior of the stream mingles with the air, and if a light be applied a flame is formed in which combustion takes place in stages around the exterior. If, however, the inflammable vapour or gas be mixed with the right proportion of air to burn it before the light is applied, an explosion takes place, and the

period taken to complete the chemical combination is so decreased that great intensity of action results, and it is upon a modification of this principle that this new method of combustion is founded.

Professor W. A. Bone has found that ·if a mixture of a combustible gas with air be forced under pressure through a porous diaphragm of asbestos and fireclay, if the mixture be ignited as it leaks through the porous mass, it cannot explode, but burns in the porous surface of the diaphragm and quickly raises it to a very high degree of incandescence, capable of yielding a very large proportion of its heat as radiant heat.

The physical condition of the porous material has a considerable influence upon the combustion; rise of temperature will greatly increase the activity of the surface, and with increase of temperature the difference which exists in the activity possessed by various substances is reduced until at bright incandescence they all have the same degree of activity.

There are two ways in which the porous material is employed in practical work. In the first, called the Diaphragm process, the materials are moulded into a plate or diaphragm, which is set in front of a small fuel

chamber. Through this plate the mixed gas and air, in the right proportions to give complete combustion, are forced under the pressure necessary to drive them through the plate. The combustible mixture is ignited on the outer surface of the plate, and burns there with a flame for a few seconds, but as the plate becomes heated the flame sinks down and combustion continues within the pores of the plate close to the surface, which is thereby raised to a state of high incandescence.

The texture of the plate can be arranged to suit the quality of the gas to be burnt, the pores being finer with rich gases than when gases of low calorific power are employed, and the pressure used is sufficiently high to prevent any risk of back-firing or explosion. The diaphragm can be fitted in any position with regard to the object to be heated to suit special conditions.

In the second method, called the Granular bed process, the refractory material is worked up into granules of suitable size, and the mixed gases are blown on to or through a mass of these under pressure. Combustion ensues on the surface of the granules, and a temperature of 2000° C. can be attained. The granules form a very convenient and

adaptable method of obtaining the desired result, as they can be packed into boiler tubes, round crucibles for melting metals, etc., or formed into a bed for furnace work. Excellent results have been given by boilers fitted in this way, and it is claimed that an efficiency of 95 per cent. has been attained, the normal rate of evaporation being 20 lb. per square foot of combustion surface, which can be increased to 80 lb. with a slight loss in efficiency, whilst any incrustation formed on the tubes from the water scales off as quickly as it is deposited.

The interest in this process with regard to liquid fuel is that it will work just as well with air carburetted with petrol vapour as with any other form of inflammable gas, so that if with an ordinary air-gas machine the mixture be arranged to contain about $2\frac{1}{2}$ per cent. of vapour, a splendid heating effect will be obtained, whilst with the material packed in tubes it forms an excellent water heater.

The latest development of all is that if oil fuel be finely atomised with air in the right proportion and then be blown into the tubes containing the granular material in the Bonecourt boiler, providing that the granular mass has first been heated, complete combustion

ensues, and the same high efficiencies can be obtained as with gas burnt in the boiler.

The value of a fuel depends to a very large extent upon the heat given out in its combustion, and this can be determined (*a*) by analysing the fuel and calculating from the result of the analysis the calorific value, or (*b*) by burning the fuel in an apparatus designed for the purpose of measuring the evolution of heat, and known by the name of a 'calorimeter.' The first attempts to measure the heat generated by the combustion of various fuels in oxygen were made by Andrews, Favre and Silbermann, Thomson, and others, but their results showed slight discrepancies, and at the present time the figures obtained by Berthelot in his bomb calorimeter are those generally accepted. The following table shows the heat units evolved by various gases, etc., as determined by Berthelot :—

	Calories.	B. Th. U.
Hydrogen . . .	34,500	62,100
Carbon to carbon dioxide .	8,137	14,647
Carbon to carbon monoxide	2,489	4,480
Carbon monoxide . .	2,435	4,383
Methane	13,343	24,017
Ethylene	12,182	21,898
Acetylene	12,142	21,856
Cellulose	4,200	7,560
Peat	5,940	10,692
Naphthalene . . .	5,690	10,842
Sulphur	2,500	4,500

There are two units employed for expressing the heating value of a fuel, the one being the calorie and the other the British Thermal Unit. The calorie represents the quantity of heat necessary to raise the temperature of one kilogram of water from 0° to 1° C., and is the term mostly used in scientific investigations. The British Thermal Unit (B.Th.U.), which is the usual English engineering unit, is the amount of heat required to raise the temperature of a pound of water from 50° to 51° F.

In order to convert calories per kilogram to B. Th. U. per lb., it is merely necessary to multiply the calories by the factor 1·8, as the difference is only that of the thermometric scales in cases where the unit weight of fuel burnt is the same as the unit weight of water heated; but if a constant weight of water or fuel, say, a pound or a cubic foot, be used, then the ratio between the gravimetric as well as the thermometric scales has to be considered, and as the kilo is 2·2 lb., the 1·8 must be multiplied by 2·2, so that the resulting factor for converting calories per lb. or cubic foot to B. Th. U. will be 3·96.

In determining the calorific value of a fuel by calculation, the percentages of the various constituents as determined by analysis are

multiplied by the respective calorific values.
Thus, methane, the chief constituent of natural
gas, has a percentage composition of—

Carbon	.	.	.	75
Hydrogen		.	.	25

and the calorific value of carbon being 8137
and of hydrogen 34,500, then—

$$\frac{(75 \times 8137) + (25 \times 34500)}{100} \quad 14727,$$

which would be taken as the calorific value of
methane.

In this particular case the figure so obtained
is too high, as the heat of formation of the
compound has not been deducted. The heat
of formation of methane, which contains
16 units by weight, is 20,414 calories, so that
the corrected value would be—

$$14727 - \frac{20414}{16} = 13{,}451 \text{ calories.}$$

Actual experiment gives 13,343 calories.

This method of calculation might be applied
to any member of the hydrocarbon families
if its heat of formation be known; but other
factors have to be taken into consideration in
the calculation of the calorific value from the
composition of a substance of more complex
character. If water be one of the products of

the combustion, the amount of heat available
will depend upon whether this water escapes
as steam or is condensed to the liquid form.
The amount of oxygen also that a fuel such
as tar oil may contain has to be taken into
calculation, as this oxygen will already hâve
combined with some of the combustible
constituents in the fuel, thus diminishing its
total heating value. Moreover, if the fuel
contains any moisture, this will have to be
vaporised at the expenditure of some of the
heat.

Taking a tar oil as an example to show
the effect of combined oxygen, an ultimate
analysis gives its composition as—

Carbon   .   .   . 78 per cent.
Hydrogen .   .   . 8   ,,
Oxygen   .   .   . 14   ,,

Each unit of carbon on burning to carbon
monoxide evolves 8137 calories, whilst each
unit of hydrogen gives 34,500; the oxygen,
however, is already in combination with
some of the hydrogen, and we know that 16
parts by weight of oxygen combine with 2 of
hydrogen, so that if we divide the percentage
of oxygen by 8, it will give the number of
units of hydrogen already in combination,
which must be subtracted from the total

percentage before being multiplied by 34,500. Then—

$$\frac{78 \times 8137 + \left[(8 - \frac{14}{8}) \times 34500 \right]}{100} = 8503 \cdot 11 \text{ calories}$$

and $8503 \cdot 11 \times 1 \cdot 8 = 15305 \cdot 59$ British Thermal Units.

The evaporative value may then be calculated from the thermal value, in the case of calories, by dividing by 536·5, the latent heat of steam on the Centigrade scale; or by dividing the B. Th. U. by 965·7, the latent heat of steam on the Fahrenheit scale. Then—

$$\frac{8503 \cdot 11}{536 \cdot 5} = 15 \cdot 8 \text{ kilos or grams evaporated from and at } 100° \text{ C., and}$$

$$\frac{15305 \cdot 5}{965 \cdot 7} = 15 \cdot 8 \text{ lb. of water evaporated from and at } 212° \text{ F.}$$

A very usual formula for obtaining the evaporative power direct from the percentage composition in lbs. of steam from and at 212° F. is—

$$0 \cdot 15 \left[C + 4 \cdot 28 \left(H - \frac{O}{8} \right) \right]$$

which with our tar oil would give—

$$0 \cdot 15 \left[78 + 4 \cdot 28 \left(8 - \frac{14}{8} \right) \right] = 15 \cdot 7.$$

In this formula the hydrogen is taken as having 4·2 times the heating value of carbon, whilst the 0·15 is obtained by dividing the calorific value of the carbon, 8137, by 965·7, the latent heat of steam, multiplied by 100.

There are many objections, however, to the calculation of the thermal value of a fuel from analysis of the material, and by far the most satisfactory method is by direct determination of the heat evolved during combustion in a calorimeter.

There are several types of calorimeter, but in all of them the principle relied on is to burn the fuel to be tested in a vessel entirely surrounded by water, the heating power being calculated from the increase in temperature of the water.

Calorimeters can be divided into the types—

1. Those in which combustion is effected by mixing the fuel with a solid oxidising agent, as in the Lewis Thompson calorimeter.

2. Those in which the combustion is carried on in an atmosphere of oxygen, (*a*) the temperature of the escaping gas not being determined, as in the William Thomson calorimeter, and (*b*) the temperature of the escaping gases being under control, as in the Fischer calorimeter.

3. Combustion with oxygen at constant volume, as in the Berthelot and Mahler bombs and the various modifications of these calorimeters devised in recent years.

Of all these types the most accurate and best is without doubt the bomb, and it is the only one in which the calorific value of liquid fuel can be determined. In Mahler's calorimeter the bomb consists of a closed cylinder of steel, the interior of which is coated with porcelain to protect the metal from corrosion by any acid formed during the combustion. The cover screws down on to the bomb, the joint being rendered gas-tight by a leaden washer, and through the cover pass the tube for leading in the oxygen fitted with a screw-down valve, and also an insulated rod, to the lower end of which a platinum rod can be attached by a small clamp. A second platinum rod also passes through the cover, being metallically connected with it, and to the lower end of this can be clamped the platinum dish which holds the sample to be tested. The two lower ends of the platinum wires are connected by a thin iron or platinum wire, which rests on the sample of fuel oil mixed with kieselguhr or other non-combustible body, and can be made red hot by

an electric current, and so serves to ignite
the charge.

In actual working the weighed quantity of
liquid fuel is poured on to kieselguhr or other
inert non-combustible matter in the platinum
dish, which is clamped on to its rod, and the
two rods are connected by a piece of fine iron
wire which rests on the charge. The cover is
screwed down tightly, and oxygen admitted
from a cylinder of the compressed gas till
the pressure gauge indicates 25 atmospheres.
The valve is then screwed down and the
oxygen tube removed. The bomb is placed
in the calorimeter vessel, which has been
previously filled with about 2·25 litres of
water, and the water is thoroughly agitated
by means of the stirring vanes. After the
temperature of the water has been noted,
the charge is fired by means of an electric
current passed into the bomb by the platinum
rods, and the stirrer is kept going continu-
ously. The temperature of the water is noted
at regular intervals till it reaches a maximum
and then falls regularly, and then for about
another five minutes to determine the rate
of cooling. The bomb is now taken out of the
water, the oxygen and other gases allowed to
escape through the valve, and the cover

removed. The interior of the bomb is rinsed out with distilled water to collect any acid products of the combustion, which can then be analysed.

The results are calculated as follows :—

D—observed rise 'in temperature.
a—correction for radiation.
P—weight of water in calorimeter.
p—water equivalent of bomb and accessories.
x—calories due to nitric acid formed.
y—calories due to sulphuric acid formed.
W—weight of oil taken.

$$\text{Calories per gram} \;=\; \frac{(D+a)\,(P+p)-(x-y)}{W}$$

The nitric acid is estimated by titrating the washings from the bomb after the combustion with a standard solution containing 3·706 grams of sodium carbonate (Na_2CO_3) per litre, one cubic centimetre of this being equivalent to ·0044 gram of nitric acid, the heat of formation of which is one calorie, which gives directly the number of calories from the number of cubic centimetres of standard alkali used. The sulphuric acid is estimated by precipitation with barium chloride, and the weight of the barium sulphate formed

multiplied by 100 gives at once the number of calories to be subtracted.

The fluidity or viscosity of an oil is one of its important characteristics, and several forms of apparatus have been devised to determine this property.. The Redwood viscometer is the one generally adopted in England. It consists of a silvered copper cylinder for containing the oil, fixed in a copper bath. The bottom of the cylinder is slightly conical and the apex is furnished with an agate jet, which can be closed by a small brass ball at the end of a wire, the ball fitting into a small depression in the agate. The amount of oil is fixed by a bent and pointed wire attached to the side of the cylinder, and a clip is also provided for carrying a thermometer. The water-jacket is furnished with revolving vanes for agitating the water and with a thermometer, and there is a side tube of copper fixed to the bath by means of which it can be heated by a flame. The whole apparatus is mounted on a tripod stand furnished with levelling screws.

To make a test the water-bath is filled with water or other suitable liquid to a height corresponding to the bent wire in the oil cylinder, and after the water has reached the

desired temperature, the oil is poured into
the cylinder to the top of the gauge. Below
the jet a narrow-necked flask with a 50 c.c.
mark on the neck is placed in a vessel con-
taining some liquid at the same temperature
as the oil. The ball is raised from its seat in
the jet, and a stop-watch started at the same
moment; the number of seconds taken by
the oil to flow up to the 50 c.c. mark on the
flask is noted, and the results brought into
comparison with the viscosity of rape oil,
that being the oil with which the apparatus
is standardised. The number of seconds taken
by the flow of 50 c.c. of the sample is multiplied
by 100 and divided by 535 (the number of
seconds for rape oil at 60° F.); the product
is multiplied by the specific gravity of the
oil, and divided by 0·915 (the specific gravity
of rape oil at 60° F.); the result gives the
viscosity of the particular oil under test. The
time occupied by the flow of 50 c.c. of water
at 60° F. is 25·5 seconds.

CHAPTER VII

THE PRODUCTION OF POWER BY PETROLEUM

IN THE INTERNAL COMBUSTION ENGINE

The conversion of heat of combustion into power—
Efficiency—The growth of the internal combustion
engine—Gas engines—The petrol or volatile liquid
motor—The heavy oil engine—The principle on
which they work—Explosive mixtures—Carburetting
—The vaporisation of heavy oil—Classes into which
heavy oil engines can be divided—The Diesel engine
—Forms for marine use—The four-stroke cycle—
Compressed air for starting and fuel injection—
Considerations   governing the choice of cycle—
Handiness for manœuvring—The engines of the
Selandia, and the results of trials—Fuel oil con-
sumption.

So far we have considered oil as a source of
power solely from the point of view of burning
it under the most favourable conditions to
generate steam, and utilising this for power
production in the steam engine or turbine.

Under these conditions the efficiency, *i.e.*
the percentage of the heat units present in the
fuel converted into power, is small, amount-
ing only to about 8·6 with the steam engine
and 12 per cent. with the turbine; but if the
oil can be used direct in the so-called 'internal

combustion engine,' in which the power is
created by the pressure exerted upon the
piston by the explosion of a mixture of oil
vapour and air in the cylinder, a great increase
in efficiency is gained by eliminating the losses
incidental to the intermediate stage of pro-
ducing steam, so that in the latest form of
oil engines using heavy oil an efficiency of
32 to 35 per cent. can be obtained, or four
times as much as with the ordinary engine.

The internal combustion motor or engine
was in the first instance made for use with
coal-gas, and as it approached success the
desire to be able to use it for motive power
led to the attempt being made to employ
the vapour of light hydrocarbons and other
volatile combustible liquids in place of coal-
gas, and this eventually has resulted in such
a revolution in traction that horse-drawn
vehicles are threatened with extinction, whilst
we owe the progress made in aviation entirely
to this convenient form of portable power.

In the early days, however, of the experi-
ments on volatile liquid motors, the ease
with which the liquid evaporated, its liability
to form explosive mixtures with air and the
danger of fire seemed such insurmountable
difficulties to its use that many engineers

turned their attention to the making of
engines that should be able to employ oils
of the character legalised for lamps—*i.e.*
with a flash-point as determined by the
Abel closed test of over 73° F., and this line
of research gave us what are known as 'heavy
oil engines.'

Whilst progress was being made in liquid-
fuel motors, the gas engine had been perfected,
and it had been discovered that high-quality
coal-gas was not by any means a necessity
for use with it, but that fuel gases, such as
those made in producers of the Dowson type,
in which steam and air were forced through
a mass of incandescent coke or anthracite
and yielded a gaseous mixture of hydrogen,
carbon monoxide, and nitrogen, could be
effectively utilised; and also that blast-furnace
gas could be employed, which gave an enor-
mous impetus to their use, and has resulted in
the suction-gas plant, which has revolutionised
the generation of power for manufacturing
purposes.

At the present time the internal combustion
motor plays not only the most important
part in power production, but also in fuel
economy, and the engines may be divided
into three main classes—

1. The gas engine.
2. The petrol or volatile liquid motor.
3. The heavy oil engine.

In all of these the principle is the same—an explosive mixture of either gas, vapour, or spray, with air, is injected or sucked into the cylinder, and is ignited. Rapid combustion or explosion gives rise to great heat, which expands the gaseous products of combustion for a moment to many times their original volume, and so creates a pressure on the piston that drives it forward.

Taking hydrogen as the most simple example, if a gaseous mixture of two volumes of hydrogen with one of oxygen were introduced into a vessel strong enough to prevent any expansion and the mixture was then fired by an electric spark, the pressure on the walls of the vessel caused by the checked expansion of the steam formed as the product of combustion would be 240 lb. on the square inch. If the two volumes of hydrogen had been mixed with five of air, this could have given two of hydrogen to one of oxygen, and if the explosion had taken place in the cylinder of a gas engine, the pressure generated would have driven the piston forward, whilst the rapid cooling of the residual nitrogen and

steam, by causing contraction, would have aided the return of the piston to its original position. When using gases containing hydrocarbons the proportion of air needed is larger, so that with good coal-gas and air the ratio would be about 1 of gas to 12 of air, whilst in a petrol engine $2\frac{1}{2}$ per cent. of petrol vapour would give the most explosive mixture.

In making an explosive mixture of the vapour of a highly volatile liquid like petrol and air very little difficulty is encountered, and all that is needed is to use a carburettor that will supply the right quantity of liquid to the air being drawn into the cylinder, when the liquid vaporises readily and gives the explosive mixture.

When, however, it comes to making the mixture of vapour and air using a heavy oil, a problem of a totally different character has to be dealt with, as the oil has first to be converted into a vapour, a high temperature being needed to bring this about, whilst during vaporisation and combustion the action must be so regulated as to prevent any formation of tarry bodies or carbon, which if produced would cause the valves to choke or stick, and so stop the working of the engine.

We have seen that all the fractions of

petroleum sold under various trade names
are mixtures of many constituents, and that
illuminating oil, or, as it is often called,
'Kerosene,' contains all the hydrocarbons of
the oil boiling between 150 and 300° C. On
attempting to vaporise such an oil it would
be found that the heat employed would bring
about such changes in its composition that
even when heated to 300° C. a large proportion
would be left unvaporised, and on pressing
the temperature higher pitch-like bodies and,
finally, carbon would be formed.

It is clear, therefore, that an attempt to
vaporise such oil by direct heat under these
conditions would not be successful. If, how-
ever, the same oil be distilled whilst a current
of hot air is passed through it, the whole of
the oil will vaporise at 200° C., and can be
distilled off without leaving any residue. In
the heavy oil engine one method of making
the explosive mixture is to spray oil in
a finely-divided condition into air and heat
the mixture, when the oil is vaporised with-
out decomposition in presence of the excess
of diluting air.

Heavy oil engines may be divided into three
classes, dependent upon the method employed
in bringing about vaporisation—

1. Engines in which the oil is converted into spray and then vaporised.

2. Engines in which the oil is conveyed to the cylinder and vaporised there by hot air.

3. Engines in which the oil is vaporised in an external device and is passed into the cylinder as a vapour.

Heavy oil engines on these principles have proved very successful on land; but for marine purposes and the propulsion of vessels of any size the Diesel type of engine, which comes under the second heading, has proved so far better suited and has made such headway that it will be sufficient to describe this type and its working.

The Diesel engine for marine purposes can be adapted to work on either the four or two stroke cycle, and also as a two-stroke double-acting engine, but each type has to be provided with an air compressor in which air can be subjected to a pressure of about 700 lb. on the square inch. In the four-stroke cycle type of engine the cylinder cover carries the various valves, in connection with the supply of fuel, the compressed air, air at ordinary pressure, and the exhaust, and these valves are actuated in the usual way by cams on the two-to-one shaft. The valves

for admitting air under normal pressure are opened during the whole of one outgoing stroke, and the exhaust during one ingoing stroke, whilst the fuel valve is arranged to open ·for a very short part of an out-stroke. The compressed air is used for starting the engine only, and when in operation is allowed to remain open for about half the stroke.

When the engine is started, arrangements are made to relieve some of the pressure due to compression of the charge in the cylinder, so that the operation can be rendered more easy: the compressed air valves are put in action, whilst the fuel valves remain inoperative, but after one or two revolutions the compressed air valves are thrown out of gear and the fuel valves begin to work, the relief pressure arrangements being at the same time put out of action.

Broadly treated, the actions which take place in the engine whilst working are as follows: In the first stroke the cylinder is charged with air under normal pressure, and on the completion of the stroke the air valve is closed, and the charge is compressed by the return of the piston to a pressure of about 500 lb. on the square inch, the temperature at the same time rising considerably.

At the top of this stroke a definite quantity
of the fuel oil is admitted into the cylinder,
and just at this moment a blast of cold air
from the compressor, at a pressure of 700 lb.
per square inch, is sent into the charge of
inflowing oil, with the result that the oil is
atomised. On entering the cylinder with its
hot compressed charge of air the oil is burnt,
and the resulting pressure drives the piston
forward on the third stroke, at the end of
which the exhaust valves are opened, and
during the return the piston sweeps the
cylinder clear of all products of combustion
ready for a repetition of the cycle on the
next stroke.

The two-stroke cycle single-acting engine
has much the same arrangement of valves on
the cylinder head, but the valve for air at
normal pressure and exhaust valve are re-
placed by scavenging air valves. The cams are
all fitted on a shaft driven at the same speed
as the engine crank-shaft. The exhaust gases
pass through ports at the lower end of the
cylinder, which are opened and covered by
the movement of the piston. The action of
the engine is as follows: The cylinder is
filled with air through the scavenging valve,
with the piston at the end of the stroke.

On the return of the piston this air is compressed to 500 lb. per square inch, as in the four-stroke engine, and similarly at the commencement of the second stroke the fuel is sprayed in by compressed air. The piston then moves outwards owing to the pressure of the combustion, and towards the completion of the stroke the exhaust ports are uncovered, the burnt gases escape through the ports, and the pressure in the cylinder falls to nearly that of the atmosphere. At this moment the scavenging valves are opened, and the remainder of the exhaust gases are swept out with some of the scavenging air into the exhaust passages. At the end of the stroke the scavenging valves are closed, and the cylinder is full of ordinary air ready for the recommencement of the cycle.

The air for scavenging the cylinder can be supplied in several ways, some makers supplying an air-compressing pump and receiver for each cylinder, whilst others provide air-pumps worked off the engine crank-shaft. Different makers also adopt different arrangements for the admission of the scavenging air, the air entering through a valve in the cylinder head in one type, whilst in another it is admitted through ports in the lower

part of the cylinder, as in the case of the exhaust ports.

As before stated, whatever the type of engine, there is required a supply of compressed air for starting and for fuel injection. This is obtained by means of an air-compressing plant worked off the main engine, the compression taking place in two stages generally, the air being cooled at each stage. The air under a pressure of about 500 lb. on the square inch is stored in a reservoir tested to withstand 120 atmospheres pressure, and fitted with a safety valve arranged to blow at 60 atmospheres. Any moisture deposited during the compression can be drained away.

Each type of engine has its advantages and disadvantages. For instance, taking the two and four stroke engines, the four-stroke means a longer and heavier engine and the valve mechanism is more complicated than in the case of a two-stroke; reversing also is a matter of great difficulty. The two-stroke engine has additional gearing for scavenging, but requires only half the number of cylinders for a given power. As regards the two-stroke double-action engine, a considerable degree of complexity is necessitated, as the pistons and rods have to be kept cool

by water circulation, the valve arrangements are more intricate, and difficulties are liable to arise in connection with the piston-rod stuffing boxes. In fairness to this last type of engine, however, it must be stated that very little experience with the large sizes has as yet been gained.

With the large powers required for marine use, opinions are divided as to the best way of obtaining the desired result, some authorities advocating the use of a number of small cylinders, whilst others prefer to employ a smaller number of large size. Where it is possible to use a heavy fly-wheel, as on land, this is a matter of small importance, but on shipboard fly-wheels, especially if of great weight, are by no means desirable, as they are detrimental to the handiness of the engine during manœuvring. With increased number of cylinders the engine responds very readily, and in a recent installation this has been well exemplified. In general the engines are started with compressed air, and after a few revolutions the compressed air starting arrangement is put out of action and the fuel supply brought into play. This means a certain amount of time, but in the installation mentioned three of the six cylinders can be

changed over to fuel whilst the remainder are
still working under compressed air; after the
first cylinders are working normally with fuel,
the second set can be changed over to fuel.
This method in practice has proved very
satisfactory.

It will be interesting to note the performance
of a vessel fitted with Diesel engines.   In
February of 1912 the *Selandia* left Copenhagen,
and after loading 2000 tons of cement at
Aalborg, continued her voyage to London.
The *Selandia* is 370 feet in length, and is
fitted with Diesel engines of 2500 I.H.P.,
which drive two propellers, whilst for the
winches, lighting, and other purposes, two
additional engines are provided, each of 250
I.H.P.

The main engines are eight-cylinder Diesel
motors, working on the four-stroke system,
the number of revolutions per minute at
normal speed being 140.   Reversing from
extremes of speeds can be effected in less
than 20 seconds.   By means of the reversing
engine the cam-shaft by which the valves are
operated is moved lengthwise after the tappet
rods and rollers have been put out of action.
When in the correct position air compressed
to 20 atmospheres is admitted to the cylinders

through the starting valve, and when the engine has attained a sufficient speed under this compressed air the starting handle is moved farther, which cuts off the supply of compressed air and opens the fuel valve, and the speed of the engine can be regulated by the position of the starting lever.

The speed of the engine is governed by an ordinary control acting on the fuel supply, closing the fuel valve when the speed gets excessive, and opening as the number of revolutions per minute decreases.

Owing to the number of cylinders and the position of the cranks, the engine is always ready to start; but, in addition, the engines can be rotated by an electric motor which is arranged to drive a small fly-wheel, some two feet in diameter, on the engine main-shaft, by means of worm gearing.

Each engine is fitted with its own air compressor by means of which the air supply for injecting the fuel oil can be brought from 20 atmospheres to 60, but each pump is capable of supplying the two engines in case any accident should put one of the pumps out of action. As a further safeguard, one of the cylinders of the main engine is so arranged that with a slight alteration in the exhaust

valve it can be made to work as a compressing
pump to bring the air pressure up to 20
atmospheres.

Each of the auxiliary engines, of 250 I.H.P.,
is fitted with air-compressing pump and
dynamo, the former of which is used for
pumping the air to a pressure of 20
atmospheres for reversing purposes and for
supplying the main-engine pumps with air
for injection.   The dynamo supplies the
necessary current for lighting the ship and
for working the various auxiliary engines,
such as winches, refrigerating plant, pumps,
etc., in addition to which are duplicate sets
of electrically-driven pumps for lubricating
oil, circulating pumps, hot and cold water
pumps for the sanitary arrangements and
bilges, etc.   One small steam boiler is also
provided which furnishes the means of heating
the vessel, and in case of need supplies steam
for fire extinction in the event of a fire in the
holds, and also works an air-pump, by which
air can be compressed to 60 atmospheres.

The electrically-driven lubricating pumps
bring the oil from the tank at the bottom of
the ship through the main bearings, then
through the crank-shaft, connecting-rod
brasses, and hollow connecting-rod to the

crosshead brasses, from thence it passes through the piston-rod to the top of the piston, back through the piston-rod to the guides, where it is subjected to a cooling surface as the guides are water-cooled.

From the two compressors of the auxiliary motors, in which the air is compressed in three stages, a pipe is led to the siren. Settling tanks for the fuel oil are arranged on the top of the engine-room casing, the oil being pumped in by an air-driven pump in the engine-room, each tank containing enough oil for twelve hours' supply. In these tanks water and any solid matter are separated out and a clean oil ensured for the motors.

All the deck fittings, winches, and steering gear are driven by electricity supplied from the dynamo in connection with the auxiliary engines, and the only steam boiler is that which is intended mainly for the heating of the vessel, and even this is oil-fired.

The fuel oil is carried in the double bottom of the vessel, the total amount in the tanks being sufficient for a continuous distance of about 30,000 miles.

The first trip across the North Sea aroused great interest, as it was the first real practical trial of the seaworthiness and manœuvring

capacity of the motors. Throughout the voyage the machinery worked excellently, and was subjected to varying conditions, but in a smooth sea at high speed, in a heavy fog at slow speed, or in strong winds with a rather heavy sea, the engines demonstrated their reliability and adaptability, and emerged from all adverse trials with perfect success.

Records were taken of the consumption of the fuel oil, and it was found that 0·363 lb. of oil was consumed per indicated horse-power, and this includes not only the power developed by the main engines for the actual propulsion of the vessel, but also the oil used by the auxiliary engines. The total consumption of oil, therefore, will be 0·363 lb. × 2500 I.H.P., this representing its use for power only, and not including the amount used for the heating of the vessel.

The most important contribution to our knowledge of the use of the Diesel engine for sea-going vessels is the paper by Mr J. T. Milton, in the transactions of the Institute of Naval Architects for 1911; whilst a paper by Mr I. Knudsen, on the trials of the *Selandia* in 1912, give the practical results.

The variation in fuel consumption for the Diesel engine with size of cylinder is very low,

as compared with many other types, the figures most usually quoted being per Brake Horse Power :—

25 H.P.	.	.	.	·49 lb. per B.H.P
33 H.P.	.	.	.	·48	,,
40 H.P.	.	.	.	·46	,,
50 H.P.	.	. ·.	.	·44	,,
80 H.P.	.	.	.	·42	,,
135 H.P.	.	.	.	·42	,,
150 H.P.	.	.	.	·41	,,

The launch of the *Hardy*, the first British destroyer fitted with Diesel engines for propulsion, in October, 1912, marks a new advance.

For full speed, turbines fed from oil fuel fired boilers will give the power; but the Diesel engines will be used for cruising speeds, at which the turbine shows a marked falling off in efficiency.

From the results obtained afloat in steam-raising on board cargo vessels of similar tonnage, the relative values of Welsh steam coal and fuel oil may be taken as—

Coal	.	.	.	.	100 tons.
Oil	.	.	.	.	66 ,,

i.e. a saving of 34 per cent.; whilst the same power would be obtained in a vessel of the same tonnage, fitted with Diesel engines, with a consumption of 18·18 tons of Solar

oil, a saving of 81·8 per cent. as against coal, and 72·5 per cent. as against oil used for steam.

It must always be remembered, however, that such figures give a very false idea of the economy to be found in the use of oil fuel, as this consists largely of saving in labour, stowage space, and the more even speed attained owing to the necessity of cleaning and clinkering the fires being done away with—a factor of the greatest importance in tropical seas.

CHAPTER VIII

THE USE OF PETROLEUM IN LIGHTING, LUBRICATION, ETC.

The inception of mineral oil lamps—The grade of oil used—The principles on which the lamp is made —The wick and its work—The supply of air— The economy of the oil lamp—The light emitted— The dangers of the oil lamp—Oil lamps for incandescent mantles—The difficulties to be surmounted— The Kitson burner—Air-gas—Saturation processes —Van Vriesland process—Safety air-gas—Hooker and other processes—True oil-gas—The decomposition of oil by heat—Young and Pintsch processes— Railway lighting by oil-gas—Blau gas—Carburetted water-gas — Lubrication — Mineral and vegetable lubricants—Vaseline—Technical uses—Paraffin wax —Ozokerit—Asphalt—Bitumen.

THERE are many uses to which petroleum is put outside the creation of power, which is a comparatively modern application, and chief amongst these are lighting and lubrication.

From the earliest days of which we have record oil lamps have been used, but until the middle of the last century it was vegetable and animal oils only that were used. Olive, colza, and other vegetable oils held the

market for this purpose until the end of the eighteenth century, when sperm oil was introduced, whilst the history of the inception of mineral oil lamps has already been told, and forms an important epoch in the°history of shale oil. We have seen that the natural oil as it leaves the well is a complex mixture of many hydrocarbons, the hydrocarbons themselves varying in the class to which they belong. On distillation, the crude oil yields first the easily volatilised constituents of low boiling point, such as petroleum spirit and petrol, after which are obtained those distillates which have a flash-point of over 73° F., and are sufficiently fluid to rise by capillarity in the wick of a lamp, and which are known as 'lamp oil.'

When a lamp oil is burnt in an ordinary mineral oil lamp, it rises from the reservoir through the length of the wick to the flame, and in the heat created there by the combustion is converted into a mixture of hydrogen and gaseous hydrocarbons, which burn and yield the light, and the ultimate products of the complete combustion are carbon dioxide and water vapour. In order to ensure that the lamp shall burn with a smokeless flame giving the maximum illumination, and shall

emit only the products of complete combustion, several factors must be attended to. In the first place the quality of the wick must be a matter of special care, as upon this depends the supply of oil to the flame; a tightly-woven wick will not feed the flame with sufficient oil, whilst too loose a wick will cause an excess, with consequent smoking, due to the supply of air being inadequate. Before the wick is inserted in the lamp it should be well dried, and should, when in position, just fill the wick-holder without being compressed, whilst the length should enable it to reach to the bottom of the reservoir, with an inch or two lying on the bottom. To obtain the best results, the wick should be thrown away after a time and a new wick put in its place, as during the ascent of the oil the wick serves to filter off from the oil any solid impurities that it may contain, and these tend to choke the wick and hinder the capillary action.

The wick should not be turned up to the maximum when the lamp is first lighted, partly for the sake of preventing the glass of the chimney being cracked by the sudden heat, and also because for the first few moments the draught up the chimney is not

sufficient to completely burn the oil. Without
the chimney the oil burns with a lurid smoky
flame, owing to its being unable to get the
necessary oxygen for its complete combustion,
and to supply this an artificial draught has
to be created, which is effected by means of
the chimney, or, as in the earlier lamps, by
a small fan actuated by clockwork in the base
of the lamp, the current of air being checked
and rendered more steady by perforated
metal baffles and similar devices, and suitable
discs or cones are employed to direct the
current of air on to the flame where
required.

The duty of an oil lamp depends upon the
amount of light that can be obtained from the
oil. The results obtained in domestic prac-
tice rarely attain the efficiency found in
a laboratory test, but the figures given by
Sir Boverton Redwood on the amount of
light obtainable from an oil are those which
are generally accepted.   With a duplex
burner a light of about 28 candles was emitted,
the consumption of oil averaging 50 grains
per candle per hour; with an argand burner,
38 candles were obtained, the oil being burnt
at a rate of about 45 grains per candle per
hour. The following table gives the results

from a selection of lamps in use at the present day:—

Type of Lamp and Name.	Grains of Oil per Candle Power per Hour.		Total Candle Power.	
	American	Russian	American	Russian
Circular wick—				
Veritas—60 line .	64·5	112·5	112·5	78
„ 30 line .	43·5	50	60	60
„ 20 line .	43·75	58·5	40	35
Ariel—12 line—⎫ (centre draught)⎭	52·8	70·9	18	18
Reading—14 line .	97·9	85·4	12	12
Kosmos—10 line .	63·9	97·2	9	9
Wizard—15 line .	56·0	51·3	18	19
Flat wick, single—				
Wanzer—no glass	42·6	48·3	17	15
Solid slip gauze⎫ and cone . .⎭	84·4	84·4	8	8
Old slip, fixed gauze	60·9	89·3	7	7
Flat wick, duplex—				
Feeder wick .	56·2	55·7	20	22
Ordinary . .	51·2	46·6	20	22

American oil—Sp. gr., 0·7904; flash-point, 110° F.
Russian oil—Sp. gr., 0·823; flash-point, 83° F.

From the above table it will be seen that the American and Russian oils give practically the same result with the flat wick, but that with circular wicks the American oil gives a far better result than the Russian, although with prolonged burning this difference is greatly lessened. When used in heating stoves, the two classes of oil give much the same sort of result.

The oil lamp naturally finds its largest field
in country districts where coal gas is either
non-existent or expensive; but the risk of
accident is a great drawback to its popularity.
If ordinary precautions be taken and only
lamps of approved pattern be used, theré is
no reason why lighting by oil lamps should
be more dangerous than when other illumi-
nants are employed. The cheap lamp is
a constant source of danger, whilst glass
reservoirs have been a fruitful source of
accident. An oil lamp should never be filled
whilst it is burning, and before it is lighted
the reservoir should be filled up to its
limit, this doing away with the chance of
the formation of an explosive mixture of oil
vapour and air above the oil. A lamp once
lighted must not be moved about, and when it
is desired to extinguish the flame, if it is not
fitted with a proper extinguisher, this must
be done by first turning the wick down and
then blowing across the top of the chimney,
and not by blowing down the chimney.

So universal has been the adoption of the
incandescent mantle with coal-gas that
attempts have been made to adapt the
mantle to the oil flame, but the difficulties
attending success are very great. So rich

are the hydrocarbons of the oil-gas flame that considerably more air is required to be mingled with it than with coal-gas. A non-luminous flame can be obtained without much ·trouble when coal-gas is burnt, but if the flame be superheated it will become to a certain extent luminous again, as the increased temperature causes the decomposition into carbon and hydrogen of the hydrocarbon molecules in the gas, which was prevented when the gas was cool by their separation and dilution with air. If a mantle be placed on such a non-luminous flame the superheating caused by the mantle itself will have the same result, and in consequence the mantle is soon coated with carbon and its illuminating power largely decreased. If an increased proportion of air be admitted to the flame, the hydrocarbons are burnt up before they can be decomposed by the heated surface of the mantle, and there is no deposition of carbon.

The wick also was found to be a source of trouble, as if not perfectly symmetrical the flame was irregular, and the correct adjustment of the working was upset, with the result that carbon was evolved copiously. In the later lamps the wick served merely

to draw the oil up into a vaporising chamber,
where it was gasified. The first lamps had
a circular wick bringing the oil to within
a short distance of the burner-head, the heat
conducted from the flame being sufficient to
vaporise the oil.   A central air-draught was
provided, and a second air supply was
arranged to meet the base of the flame almost
horizontally, but although in careful hands
these lamps fulfilled their claims, yet as a
commercial article they were a failure, owing
to the need of constant attention and the
irregularity of their performance.

In another lamp oil and water were vapour-
ised by a separate flame in the body of the
lamp, and the resulting mixture of oil-gas
and steam was led to the burner-head, where
it was burnt with a special arrangement of
air supply to heat a mantle, but this again was
too complicated for everyday use, and so
sank into oblivion.

One of the most successful oil lamps for
use with the incandescent mantle was that
devised by Mr Arthur Kitson, who adopted
the principle of leading the oil through a fine
tube under pressure into a chamber where it
was gasified by the waste heat of the flame burn-
ing below. The vapours, under the pressure

of the initial air pressure and their own formation, were led into what was practically an atmospheric burner, in which sufficient air was drawn in to produce a non-luminous flame, which could be employed for rendering a Welsbach mantle incandescent. A certain amount of attention is required in the use of the lamp, and when this is given success has followed its adoption.

When used for street lighting, the oil reservoir is placed in the base of the lamp, the reservoir being made of steel and capable of withstanding a high pressure. The air above the oil in the reservoir is pumped up to a pressure of between 50 and 60 lb., and when the valve is opened the oil flows up to the burner through a small capillary copper tube. At the burner it is filtered through a small diaphragm to remove any solid matter, and then passes into the vaporising tube placed immediately above the top of the mantle. This vaporising tube is heated initially by the flame from a small quantity of methylated spirit, the heat being after- wards maintained by the hot products of combustion from the burner. The oil-gas and vapours pass down what is practically an inverted bunsen tube, air at the same time

being drawn in by the rush of the vapour,
and by the time the mixture reaches the
burner-head, there is enough air in it to render
the flame sufficiently aerated to prevent any
deposition of carbon, and it is practically
down to atmospheric pressure again.

The exit hole from the vaporising chamber
is liable to occasional clogging with carbon
particles, so that to minimise this trouble
the vapour tube is provided with a needle
actuated by a lever and chain, by which the
tube can be cleared in the event of any
stoppage taking place. To prevent any chance
of oil escaping into the vaporising chamber
when the lamp is not in use, either through
a leaky valve or the oil supply being turned
on accidentally, a thermostatic valve is fitted
which checks the flow of oil to the vapour tube
until it is sufficiently hot to vaporise the oil
properly. The air supply is heated before it
enters the bunsen tube, which does away with
any risk of condensation of the oil vapour,
and to a large extent eliminates the objection-
able hissing sound made by the escaping
mixture.

Within the last ten years a very large
number of forms of apparatus for producing
what is known as 'air-gas' have been introduced

for the lighting of country houses and districts where no coal-gas exists. This air-gas, or, as it is termed by the Americans, 'greased air,' consists of air carrying the light vapours of petrol in suspension, which will burn when the air is sufficiently carburetted, giving a luminous flame, and can be made available for illumination also by means of the incandescent mantle.

There are two classes of these air-gas machines. In the first class the air is passed over or through petrol contained in a vessel called the carburetter, and takes up a certain proportion of the vapour of the volatile spirit, the amount being dependent upon the vapour tension of the liquid and the temperature, and the resulting mixture is necessarily very varying in its quality. When the spirit is first put in and the temperature is high, the gas formed will often be too rich in hydrocarbons, and will under those conditions burn with a smoky flame, whilst when the more volatile portions of the carburetting liquid have escaped, especially if the temperature be low, the air does not take up sufficient vapour to give proper carburation.

This system of saturating the air as far as possible to give an illuminating gas *per se* in

flat flame or argand burners, is the one which
was first employed, and was largely adopted
on the Continent. A good example of such
a system is to be found in the Aerogene gas,
which is obtained from a form of apparatus
devised by Mr Van Vriesland.   In this
arrangement a revolving coil of pipes con-
tinually dips into petroleum spirit contained
in a cylinder. Through the coil air is passed,
and becomes highly carburetted in its passage
through the cylinder. The mixture gives
a luminous flame in a flat burner, and with
an ordinary Welsbach 'C' burner about 30
candles per foot of gas consumed can be
obtained; but this high duty is largely due
to the pressure of 6 to 8 inches at which the
gas issues from the machine.

The system is employed for street as well as
for house lighting, several villages on the
Continent using it for public and private
lighting, and it has been found that, contrary
to expectation, there has been no trouble
from deposition of condensed vapours in the
mains during cold weather; in the summer,
however, the resulting mixture is rather more
highly carburetted than in the winter, which
necessitates a slight alteration in the air
adjustment of the burners. The mixture has

been found also to travel through the mains
with but little loss in illuminating power.

In the second class of air-gas generators,
petrol or other carburetting liquid is added
in measured quantity to the air, so as to
produce a uniform mixture of 1·5 to 2·0 per
cent. of the hydrocarbon vapour with the
air, this giving a gas that will burn with a non-
luminous flame in a properly adjusted burner
and which can be made to heat an incandescent
mantle, whilst if the gas should escape into
the air the extra dilution prevents its burning,
instead of forming an explosive mixture, so
that the name of 'safety gas' is often given to
this form of carburetted air.

The reason why when this gas is mixed
with air it ceases to be explosive is that when
petrol vapour is added to air it is found that
1·25 per cent. of vapour gives a flame that will
just travel through the mixture; combustion
becomes rapid when the percentage rises to
1·5 per cent., and becomes explosive at 2 per
cent., the maximum explosive force being
reached at 2·6 per cent., after which increase
in the quantity of vapour causes a diminution
in explosive violence until 5 per cent. of the
vapour is present, when the gas ceases to
become explosive and burns quietly once

more. If now a gas, which contains 1·5 per
cent. of the vapour and, therefore, burns
steadily, be mixed with more air, it is so
diluted as to be beyond the explosive limit.

It was Hooker who first utilised this
principle some twelve years ago, and since
then nearly all the air-gas apparatus makers
have adopted this idea, as it enables 1400 to
1500 cubic feet of air-gas to be made per
gallon of petrol, and when this is burnt under
an incandescent mantle the light yielded is
about 9 candles per cubic foot.

In the present-day machines the petrol is
added to the air in measured quantity auto-
matically according to the requirements of the
gas consumption, each added portion of petrol
being made to volatilise entirely in its definite
amount of air, by which means a gas of
uniform quality is produced. This result can
never be obtained with carburettors which
depend on the air passing over the surface or
bubbling through the petrol, as these methods,
as before stated, yield a gas of very varying
composition.

The air is forced through the machine by
devices actuated by any convenient source of
power, such as a falling weight, water power,
clockwork, or small hot-air engine, the last

being the one usually adopted, as the engine being driven by the combustion of a small portion of the gas itself, renders the apparatus self-contained. The air passes into a chamber, where it meets with the correct proportion of petrol, and is thereby carburetted. To secure instantaneous and absolute vaporisation of the petrol, various ingenious forms of apparatus have been devised. In one type the liquid is injected into the chamber as a spray, in another the liquid drops on to the surface of a ball, round which the air is made to circulate, whilst in a third the petrol and air are violently agitated in the carburetting chamber; in each case the resulting compound passes into a mixing chamber and on to a small holder.

The burners used with air-gas will vary in construction according to the quality of the gas with which they are used.

If the mixture contains less than 2 per cent. of vapour, it is already provided with sufficient air to give a non-luminous flame, so that no aeration is needed at the burners; but the tubes are fitted with wire gauze screens or some such arrangement to prevent any chance of a back-fire in the event of an explosive mixture being formed in the generator. With

the richer mixtures containing more than
5 per cent. of vapour the ordinary type of
bunsen burner is employed, in which the ratio
of gas and air can be adjusted very delicately.
With every type of apparatus, however, it is
essential that there should be some form of
safety chamber between the generator and
the burners to obviate the risk of explosion
due to a flash-back.

True oil-gas is made by decomposing either
shale oil or petroleum by heating it in a
retort at temperatures a little below 1000° C.,
when it decomposes into gases and vaporous
hydrocarbons, and leaves behind a residuum
of carbon. The gas so formed, after condensa-
tion of the vapours from it, will amount to
about 800 cubic feet of 40 to 45 candle gas
per gallon of oil decomposed.

There are two methods by which this decom-
position can be carried out, the first being
processes of the kind used by Pintsch in
making oil-gas for railway carriage lighting,
whilst the second process was introduced by
Mr W. Young in making oil-gas intended for
the enrichment of coal-gas. These two pro-
cesses may be described shortly as follows :—

In the Pintsch process D-shaped iron retorts
are employed, about 10 inches high and 6 feet

long, placed in pairs one above the other, each pair being connected vertically. The oil flows into the upper retort, at a rate which can be finely regulated by a suitable tap, and enters the retort by means of a siphon fitted in the retort lid, the end of the siphon inside the retort being about 12 inches long. The oil drops on to a sheet-iron tray in the first retort, where it gets heated and vaporised, and the resulting gas passes down into the lower retort, which is at a higher temperature, and is there 'cracked' and rendered permanent. From the second retort the gas enters the hydraulic main, and after passing through a scrubber is stored in a holder. In order to test the temperature of the retorts they are each provided with a small tap, and from the colour of the gas as it issues from the tap it is possible to ascertain how the decomposition is proceeding. The correct colour of the gas should be a pale straw; but should it be brown or black, the temperature of the retort is too high and should be reduced, or the flow of oil must be increased.

The object of the decomposition of the oil is to obtain rich oil-gas with pitch or carbon only as a residuum, as any tar that may be formed has but little commercial value. To

attain this result attempts were made to fit
a condenser above the retorts, so that any
liquid condensed there might fall back into
the retort and be subjected to a further
heating.   This   idea   was   elaborated   by
Young, who decomposed the oil at a moderate
heat and subjected the resulting gases to
washing by the inflowing oil. In this way all
condensible vapours were washed out and
only permanent gases allowed to pass on to
the holder. The oil which had dissolved out
the condensible vapours was then run into the
retort and decomposed, so that there was no
loss of material.

   The retorts, which are of iron and about
10 feet long, are set with a downward inclina-
tion to the back, and each is fitted with the
usual mouthpiece and ascension pipe and
tap for testing the colour of the gas, which
should be, as in the previous system, of a pale
straw. About two feet up the ascension pipe
is a small tap through which the oil is admitted,
and the oil drops through the ascension pipe
on to a steel plate about three feet long fixed
in the retort, which serves the purpose of
protecting the bottom of the retort from
the direct impact of the oil. From the retort
the gas passes through the hydraulic main

and condenser to the scrubber, through which
the oil from the supply tank is allowed to
flow, and finally the gas enters the holder.
After flowing down through the scrubber, the
oil travels back along the condenser and
hydraulic main to a small cistern, from which
the supply can be regulated to the retorts.
The oil employed is what is known as 'blue
shale oil,' and the residue of the decomposition
is a very dense form of coke.

The following table gives the composition
of the gas made by the two processes :—

	Pintsch.	Young
Candle power . .	50	60
Unsaturated hydrocarbons	33·16	43·83
Saturated hydrocarbons .	45·15	36·30
Hydrogen . . .	19·65	16·85
Carbon dioxide . . .	0·50	0·63
Carbon monoxide . .	0·50	0·00
Oxygen	0·60	1·14
Nitrogen	0·44	1·25
	100·00	

For the lighting of railway carriages and
buoys the oil-gas is compressed into steel
cylinders, fitted with a reducing valve. From
the cylinders the gas is led to the burners,
which are generally of the flat-flame type,
consuming about one cubic foot per hour, and
yielding a light of about 8 candles per burner.

In the lighting of railway carriages an improvement in the light emitted was effected by using small regenerative burners instead of flat flames, and also by adding a percentage of acetylene to the oil-gas. The most brilliant result, however, is attained by burning the oil-gas in a small inverted burner which renders an incandescent mantle luminous. The upright mantle was found to be useless for this purpose, as the excessive vibration rapidly led to its destruction, but the method by which an inverted mantle is suspended from the burner annihilates the vibration to a very large extent, and in the event of the mantle being broken the continuance of the light is secured by enclosing it in a wire cage, by which it is kept in contact with the flame.

A very interesting modification of oil-gas has lately taken place with the introduction of what is known as 'Blau gas.' As we have seen, oil-gas is a mixture of many hydrocarbons which, although gaseous at ordinary temperatures, can be liquified readily by cold or pressure. If oil-gas be subjected to a moderate pressure the vapours and volatile liquids present in it separate out and can be drained off. If the remaining gases be cooled and brought under a higher pressure, certain

gaseous hydrocarbons condense to the liquid
form, but the liquid so produced differs from
the liquid hydrocarbons separated at low
pressure in that as soon as the pressure is
relieved it will gasify again, whilst the other
liquids would not. By adopting this principle
a liquid is obtained and stored in steel cylinders
fitted with a reducing valve, and on opening
this valve the liquid is reconverted wholly
into gas of high illuminating value, so that
a comparatively small cylinder can be utilised
for the development of a considerable amount
of light, this being of great use for signalling,
buoys, etc.

In America the gas from the petroleum
wells, which is rich in the lightest forms of
petroleum spirit and also in gases like ethane,
propane, and butane, is in many cases con-
densed by cold and pressure, and this liquid
gas, under the name of 'Gasol,' stored under
a pressure of 500 lb. on the square inch, is
used for illuminating places where no gas is
present; one volume of the liquid gasol yields
about 850 volumes of gas when released from
pressure.

Oil-gas is used to a very large extent in
rendering luminous the gas made by passing
steam through incandescent coke, which

consists of a mixture of carbon monoxide and
hydrogen, and is known as 'water-gas.' This
mixture is perfectly non-luminous, and can
be used as a substitute for coal-gas only when
luminosity has been given to it by admixture
with the highly illuminating oil-gas.   This is
generally effected by decomposing the oil in
the presence of a stream of red-hot water-gas
passing from the water gas generator, and the
form of apparatus mostly in use is known as
the Lowe plant, which, first made in America,
has been modified and improved by Messrs
Humphreys and Glasgow.

In this system the fuel is blown up to
incandescence by an air blast in the generator,
and the producer gas so formed is burnt in the
carburetter and superheater, which are heated
by the combustion to the necessary tem-
perature for decomposing the oil.   When the
fuel in the generator is sufficiently heated,
the air blast is shut off, and steam is blown
through it, the water-gas passing to the top
of the carburetter, where it meets the oil,
and both are carried down through the
carburetter, the oil being thoroughly 'cracked'
in its passage.   In the superheater the oil
vapours and water-gas are subjected to
another heating, which has the effect of

finishing the conversion of the oil vapours into permanent gases. The mixed gases, after being subjected to washing, scrubbing, and condensing, are ready for distribution as carburetted water-gas.

Lubricants and substances intended to reduce the friction between moving surfaces have to be endowed with certain properties to make them successful, and for general use liquid lubricants are the most convenient to employ. These consist of both vegetable, animal, and mineral oils, but the property which some vegetable and animal oils have of absorbing oxygen to form acid bodies has always been against their use. To avoid this trouble, certain fractions of petroleum distilling over after the petrol, illuminating oil, and solar oil fractions have come off, are employed largely for lubricating purposes; whilst the fractions of the oil obtained at higher temperatures will in many cases become semi-solid when cold, and bodies of the character of vaseline are produced, which are not only used as lubricants, but are also employed largely in making some forms of smokeless explosives, where they serve the purpose of adding to the stability of the compound and also to give a slight coating to the gun when

fired, this preventing the metal of the gun seizing upon the surface of the projectile to form what is known as 'metallic corrosion.'

It has been discovered of late years that the 5 per cent. of vaseline used in the English Service cordite helps to give that body its superior keeping properties, especially in hot climates, this action being brought about by vaseline having the power of absorbing certain oxides of nitrogen given off by the cordite in its decomposition, which if allowed to remain in contact with the cordite would expedite its breaking up, and might even lead to spontaneous ignition.

We have seen that in the distillation of shale oil a residue containing paraffin scale is obtained. This paraffin scale when separated from the oil and purified yields a beautiful white wax, from which paraffin candles and insulating compounds can be made. This same waxy substance can be obtained by the destructive distillation of peat and other vegetable remains, whilst small quantities are also got from some forms of petroleum.

In certain districts, especially in Galicia, deposits of a natural wax are found, called ozokerit, of much the same character as the paraffin wax. This substance is carefully

mined, and after decolorisation and purifica-
tion yields a material much valued for making
protective paints and compositions, and also
for the manufacture of candles.

In some oil districts where a slight leakage
of petroleum has taken place from a fractured
anticline, the oil filtering up through the over-
lying strata becomes oxidised and converted
into asphaltic and bituminous compounds of
the character of those used for road-making,
the asphalt rock used for this purpose con-
taining a sufficient percentage of the asphaltic
body to cause it to bind together into a hard
mass when laid in layers and heated by a red-
hot pressing-iron.

Where oil, escaping from some underground
source, undergoes a natural process of distil-
lation which simply drives off from it the
lighter portions, it forms a thick pitch-like
residuum which forces its way into cavities
and faults in the surrounding strata, and is
found there as a black jet-like material,
forming intrusive veins some little distance
from the oil deposit that gives rise to it, such
pure bitumens as manjak, gilsonite, etc.,
having been formed in this way.

Many attempts have been made to render
petroleum solid, and several processes have

been patented for this purpose. The method
generally adopted is to mix the petroleum
with a resin soap, obtained by heating resin
and caustic soda; the resulting solid contains
about 75 per cent. of petroleum and can be
burned without liquefying.

Besides resin soap, many other bodies
have been employed, amongst which may be
mentioned a decoction of Quillaia bark, and
of such lichens as give an extract which has
the property of setting, as well as fish glue
and casein. In one process the petroleum is
emulsified with a warm solution of glue, this
is allowed to cool in moulds, where it sets,
and the blocks are then hardened with formal-
dehyde.

A product of the consistency of vaseline can
be obtained by incorporating aluminium
oleate with about 80 per cent. of its weight
of petroleum, and the viscosity of the oil
can be largely increased by the addition of
the fat extracted from wool.

CHAPTER IX

THE FUTURE OF PETROLEUM AND OIL FUEL

The supply of oil and likely duration—Lesley on the
life of the oil fields—Signs of exhaustion in existing
fields—Causes that lead to abandonment of wells—
The oil fields of the future—Waste of oil—The
influence of the demand for petrol on the supply of
fuel oil—The economies that can be practised—The
importance of developing the Diesel type of engines
—The cost of petroleum—The influence of local
demand and freight—The importance of rapidly
developing the oil fields of the Empire—The future
of motor spirit.

In considering the future of oil fuel there
are two outstanding points which in import-
ance overshadow all others. The first is
supply and the likely duration of the oil
fields, and the second is cost; there is no
question as to use—given petroleum of the
right grade at one and a half times the price
of coal, 80 per cent. of the coal consump-
tion could be replaced advantageously by
liquid fuel.

In 1886, when the Pennsylvanian and Baku
fields were at their zenith, Professor J. P.
Lesley said: 'I am no geologist if it be true
that the manufacture of oil in the laboratory

of Nature is still going on at the hundredth
or the thousandth part of the rate of its
exhaustion. And the science of Geology may
as well be abandoned as a guide if events
prove that such a production of oil in Western
Pennsylvania as our statistics exhibit cán
continue for successive generátions. It cannot
be. There is a limited amount. Our children
will merely and with difficulty drain the dregs.
I hold the same opinion respecting natural
gas, and for the same reasons, with the
difference merely that the end will certainly
come sooner and be all the more hastened by
the multiplication of the gas wells, and of the
fire-boxes and furnaces to which it is led.'

As regards these fields events have entirely
justified his forecast, whilst the Roumanian
and Galician fields show in localised portions
the same thing. True, the output of these
latter fields shows a total increase; but when
the source comes to be examined, it is found
that the average output per well decreases,
and that the increase in the oil output is due
to an enormous increase in the number of
wells.

In the Appalachian oil fields of America,
for instance, the yield of new wells in the
early years of the century shows this clearly.

New wells drilled in 1901 gave an average yield of 16·9 barrels per day; new wells drilled in 1902 gave an average yield of 15·6 barrels per day; new wells drilled in 1903 gave an average yield of 11·8 barrels per day.

In the Baku district, where the yields of oil were far greater than in the original American districts, the life of the wells has been given as from two to nine years, although there have been cases of big yields over longer periods. It is clear that as each deposit contains only a certain amount of oil, and each well can drain only a certain area, if the area is cut up into small holdings, the proprietor will, in his own interest, put down as many wells as he can near the confines of his territory, in order to draw as much oil as possible from the deposits under his neighbours' lands, and fields thus subdivided and crowded with wells soon show signs of exhaustion.

It must also be borne in mind that when an oil well or field is said to be 'exhausted,' it does not by any means imply that there is no more oil, but that the amount of the yield has fallen below the quantity at which it can be worked profitably. Many causes lead to the abandonment of a well even before this point

has been reached—the casing of a well may
corrode or collapse, a slip or other earth
movement may cave it in, flooding of the
oil strata by overhead sources of water may
render it unworkable, or the well may become
choked with sand.

In any case, the more rapid the working
and the greater the yield of oil from any
district, the more rapid will be the exhaustion.

Mr Beeby Thompson quotes the case of the
celebrated Spindle Top field in Texas, which
with an area of only 200 acres yielded in the
four years commencing January, 1901, no less
than 4,650,000 tons of oil, after which it was
so far exhausted and flooded that only 95
productive wells remained out of 1200 wells
drilled. Subsequent development again raised
the yield in 1907 to about one-quarter the
original output.

All the evidence we can obtain points
clearly to the supply of oil from existing
fields being limited in quantity, so that,
however great the output may be, it will
last only for a certain time, and probably
fifty years may be taken as the average life
of an oil field worked under competitive
conditions.

The question now arises of how the oil

fields of the future will compare in size with those of the past and present, and here we are face to face with a problem in which the geologist must play an important part. It is now · known that the distribution of oil-bearing strata is far wider than was before suspected; but although there are several fields probably as rich in oil as the original American and Russian fields that we know of awaiting development, their number is by no means unlimited, and it is more than probable that oil will prove itself a passing period in the fuel history of the world, which will concentrate itself into the next hundred years, unless drastic means are taken to check the profligate waste of the past. Our waste of solid fuel has been a disgrace to us as a civilised nation, but it has been a waste in consumption brought about by improper methods of use and selfish disregard of what the future might bring forth for others; whilst the waste in oil has been enormously greater and of a totally different character, having been brought about by the fact that when the oil strata were tapped Nature gave up her treasure so abundantly as to render its collection practically impossible, or else, as was more often the case, no provision for

storage had been made, and the oil had simply
run to waste until tanks could be erected.

   During the next fifty years every oil field
that can be found will be developed to supply
the ever-increasing demand for petrol, and
with the same object in view processes of
distillation under pressure will be developed,
to enable the heavier distillates to be cracked
so as to yield increased volumes of the lighter
oils. The illuminating oil fractions probably
will be used less and less, and those oils
available for use in engines of the Diesel type
will be largely developed. Already improve-
ments in such engines are taking place which,
by sweeping away the complications of the
gear exterior to the cylinder and increasing
the power it is possible to create in single
units, will render such motors available for
use in vessels of high speed and great tonnage,
and this in turn will divert much of the
demand for ordinary fuel purposes into the
new channels, when the direct conversion of
the heat units in the oil into power by means
of the internal combustion motor will enable
about one-third the weight of oil to give the
power that would be required to create steam
for use in the steam engine.

   It is the demand for petrol that will govern

the oil market, and this has more than doubled
in the last five years, and shows every sign
of continuing to increase in the same ratio
for some time.   During this period, however,
the available sources have shown but little
increase; and to meet the demand so created,
all known sources of oil will be developed
irrespective of the demand for fuel oil, which,
owing to these circumstances, probably will
not be so difficult to obtain as during the
past two years.

It is very difficult in our present state of
knowledge to make any definite calculation
as to the period for which the oil supplies
will last; but even with the present demand
it is extremely improbable that it will con-
tinue at a price that will make it a com-
mercial possibility for any very long period.
Only this Spring Dr Engler computed the
world's reserves of oil at 5,000,000,000 tons,
which at the present rate of production would
only last 100 years; but if the consumption
increases at the same rate as during the past
few years, another half-century will see the
end of oil fuel as a commercial possibility.

Turning to the question of cost, there are
two factors that must influence this, the
one being local demand, which governs the

initial cost of the oil, and the second freight charges.

We can never reckon on any oil from what will probably be in the future one of the richest oil-yielding districts in the world,— the trans-Caspian area,—as this in common with the Baku, the Emba-Caspian, and other fields situated near the shores of the Caspian Sea, have their only direct outlet by shipment to the Volga, and are the natural source of supply for Russia and Germany. To make these available for the English market, they would have to be shipped to Baku, conveyed by pipe line and rail to Batoum on the Black Sea, and re-shipped from there; and it is fairly clear that this would never pay with an oil the demand for which in Northern Europe gives it a high local price. If the district east of the Caspian proves as rich in oil as many believe it to be, railway or pipe line communication with the Persian Gulf might be a possibility; but even then the freight would be as heavy as from the Dutch East Indies or Burma, and if freight alone is going to be in the neighbourhood of 80s. a ton, low-priced fuel oil is not likely in England. In the West, the Texan and Californian fields are yielding large supplies; but the American

market for fuel oil is so good that the high initial price it commands makes up for the lower freight. Much is hoped from the Taman and Maikop oil fields, as these offer direct communication with the Black Sea, and there is no doubt but that the Crimea and Kertch peninsulas will yield their quota to the oil supply, whilst even close to the Dardanelles oil exists; but these are not supplies that could be reckoned on in time of war. Austria and the neighbouring countries want all the oil Roumania and Galicia can produce, and at present our oil fuel supply can be drawn practically only from those sources which have a surplus over the home consumption.

Before England can attain an independent position with regard to oil, it is essential that not only must the shale oil industry be fostered and encouraged to the greatest possible extent, but the oil fields of the Empire must be developed, so that India, Canada, the West Indies, New Zealand, and Australia shall be in a position to aid the mother-country with liquid fuel.

The extraordinary activity which for some months past has caused a boom in oil would be enormously increased if users had any guarantee that in the event of their

committing themselves to its use a continuous
supply would be forthcoming, and that an
increase in the use of this convenient fuel
would not be followed by such a rise in price
as would render its commercial employment
impossible.

At the present time it is only in petroleum
producing countries that the price and supply
enable oil fuel to come into anything like
extended use, and even in America, the
greatest fuel oil producing country in the
world, it is only within the last two years
that sufficient confidence has been felt in the
nature and price of the supply for it to be
shown how general its use would become.
From the beginning of the century several of
the railway lines whose properties touched
some of the oil fields have been using liquid
fuel instead of solid in their locomotives, and
this has steadily grown, until last year the
railway consumption of fuel oil had risen to
27,774,800 barrels, the average mileage being
8·75 miles per barrel, and as much again was
used in America for manufacturing and other
industries.

The adoption, also, of liquid fuel by the
American Navy, in which is now being used in
much the same way as in our own Service—that

is, exclusively· for destroyers and small craft, and as an auxiliary for battleships, for which something like 20,000,000 gallons are needed annually—has turned the attention of the American Government seriously to the question of supply, and now that they have laid down two new battleships to burn liquid fuel only, they are safeguarding the Naval supply by taking the control of from 30,000 to 40,000 acres of the Californian oil fields, which will probably be held as a reserve, and would when opened up yield enough liquid fuel for a twenty-five years' supply, an example that might well be followed by our own Government with regard to some of our own Colonial oil districts.   England is at present suffering from such a shortage of fuel oil that any expansion is an impossibility; but the rate at which tank steamers are being built by the leading oil concerns encourages the hope that within the next few years a far more ample supply will be forthcoming, as it is undoubtedly at the present time lack of transport facilities and not shortage that has cramped the supply and driven up prices.

It must always be borne in mind that in the past the producing end of the system has been hampered, and in many cases

ruined, by the small demand there has been
for the heavier fractions of the oil that
constitute liquid fuel, and the present demand
for it in all quarters has found the industry
without the necessary transport facilities;
but as soon as these are provided, rapid
developments in all directions will take place.

At the present moment there is no question
of greater commercial and scientific interest
than that of our future supply of petrol, and
the means by which the increase of demand
over production that is already making itself
felt in increased price can best be dealt with
in order to avoid a serious check in what has
become almost a necessity of modern life.
In every country in the world the petrol-
driven motor has increased in use with such
rapidity that the demand for the lighter
fractions of crude petroleum, of sufficient
volatility to serve for use as a carburetting
agent, has led to a distillation and redistilla-
tion of every oil supply capable of yielding
it, and as the demand shows no sign of reduc-
tion in the rate of increase, it seems inevitable
that the price must continue to rise until the
demand is reduced either by reduction in the
number of motors used or by the introduction
of other kinds of carburetting material.

Twenty years ago the lighter fractions from the distillation of the crude oil were a drug on the market, used only as a grease solvent and to a very limited extent as an illuminant in sponge and Holliday lamps, but with the rapid rise of the motor-car these fractions proved themselves to be the ideal fuel, and from an almost waste by-product they have risen to the position of being the refiner's most paying product.

The rate at which the demand has risen may be judged from the following figures, which show the imports of petrol into this country during the past eight years :—

Year.	Gallons.	Year.	Gallons.
1905	18 millions.	1909	53 millions.
1906	25 ,,	1910	55 ,,
1907	34 ,,	1911	70 ,,
1908	40 ,,	1912	80 ,,

So that in that period the demand has been more than quadrupled, whilst in America, France, and several other countries the increase has been even greater.

During this period, however, the world's production of crude oil has increased only from 28,500,000 tons in 1905 to 50,000,000 tons in 1912, so that the crude material has been less than doubled, and it is clear that as the most prolific new fields, such as the

Californian, have yielded oil far poorer in the light fractions than the older sources, some radical alterations must be made if the English supply is to be kept at a usable price.

The chief sources of our supply during the past few years have been the American and Dutch East Indian fields, which up to a point competed vigorously for the English market, but the American spirit was only the surplus that could be spared after the home consumption had been satisfied; and as the demand in the States has increased, so the surplus available for export has diminished, until in 1912 the sources from which we drew our supply were—

Dutch East Indies . .	40 million gallons.
America . . .	16 ,, ,,
Holland . . .	6 ,, ,,
Russia . . .	5 ,, ,,
Rumania . . .	4 ,, ,,
Other Countries . .	9 ,, ,,

And the petrol from Holland came from the East Indian fields, so that more than half our supply came from fields which are owned by the Royal Dutch and Shell Companies.

The rise in price has been brought about by several factors all tending in the same direction—the shortage of crude oil to meet the ever-increasing demand, insufficient

transport facilities, and, finally, the fact that the chief source of supply is in the hands of an extremely clever group of great financial strength, who are justified commercially in recouping themselves for the years during which competition with the American market kept prices low. That the excess of demand over supply is a far more important factor than most people admit is shown by the fact that the price of crude oil at the oil fields everywhere is touching record prices, whilst the insufficiency of the transport facilities will disappear probably with the fleets of oil tankers that are now under construction and the opening of new pipe lines.

The one fact which stands out as perfectly clear is that with less and less petrol being exported from America, owing to the increase in the home consumption, it is a certainty that unless some other source can be found to supply a large proportion of our needs, prices must rise, and every possible method of creating such a supply is being scanned eagerly and passed under review.

The only sources likely to yield a sufficiently large quantity at a sufficiently low price are those portions of the petroleum outside the petrol fraction, products of the carbonisation

of coal and shale, and products of fermentation.

It is found that even with oils poor in petrol, such as the Californian crude oils, the gases given off during the escape of the oil from the well contain light hydrocarbon vapours which can be recovered from the gas by compression, and in the Oklahoma and Kansas fields about 12,500 gallons daily are recovered in this way and yield a light spirit, which on account of its great volatility is valuable for mixing with heavier grade petrols. This process is still in its infancy, and will undoubtedly spread to all the oil fields, and may increase largely the petrol supply by enabling a fraction of the kerosene distilling above 150° C to be used in admixture with it.

Already the distillation of petrol is being carried further and further into the kerosene fraction, as is evidenced by the rise in specific gravity of commercial petrol. Fifteen years ago plenty of petrol of a specific gravity of ·680 was obtainable, whilst now the bulk is ·720 for car work and often above ·740 for omnibus and trolly motors. Care, however, has to be exercised in making such mixtures, as if there is too much of the heavier fraction

there is trouble in starting the engine from cold, and it is apt to show a want of elasticity in heavy traffic, whilst with all such mixtures there is the risk of the portions *left* in the carburettor becoming what is termed 'stale,' owing to the more rapid evaporation of the more volatile portions.

Another process being experimented with largely is the distillation of the heavier fractions of petroleum in contact with catalytic agents, such as nickel, in various conditions.

One of the most promising lines, however, for increasing the yield of petrol from heavy distillates is to be found in the so-called 'cracking' of the residues in order to simplify their structure into hydrocarbons of lower gravity. The idea of distilling oil under pressure was first patented by James Young in 1865, and he found that by treating shale oil in this way the percentage of light oil was notably increased. In 1871, Thorpe and Young distilled paraffin wax under a pressure of 25 lb., obtaining in the distillate light hydrocarbons akin to petrol in gravity, and they also demonstrated and proved that on subjecting a heavy hydrocarbon to heat and pressure there is produced a mixture of

saturated and unsaturated hydrocarbons of
lower boiling point and greater volatility than
the original oil.   The same results were
obtained by Benton in 1887 under higher
pressures, whilst in 1889 Sir James Dewar and
Sir Boverton Redwood patented the distil-
lation of heavy grade oils and condensing
the products under pressure, whereby lighter
oils and spirit were produced.   At the oil
fields themselves a method of prolonging the
period of heating, resulting in an increased
yield of the lighter fraction, has been prac-
tised for some time, the tops of the stills being
left without any non-conducting coating, so
that a portion of the distilling oil condenses
there and drips back into the retort, where it
undergoes a further period of heating.

  A process which is being worked success-
fully at the present time for the production
of light fractions from a heavier grade of oil
employs for the purpose what is known as
'Solar Oil,' which is obtained from American
oil after the lighting portion has been dis-
tilled off.   The solar oil is sprayed with water
into long iron retorts packed with iron turn-
ings and kept at a temperature of 600° C.
As the water vapour and oil pass through the
retorts the oil is cracked, and the vapours

travel on to an atmospheric condenser; in this the undecomposed and heavier oil vapours condense and are returned to the retorts to be again heated, whilst the lighter portions passing on are condensed in water coolers, and the lightest spirit passing on as vapour in the gas is subjected to scrubbing by oil: the permanent gases left after this treatment going to a holder and being afterwards used for heating the retorts. The condensed and scrubbed-out products are then heated in a continuous steam still and the spirit distilled off, the residual oil from the still and first condenser being mixed with fresh solar oil and passed through the retort again.

Most promising results have been obtained by this method, 39 gallons of petrol being obtained from 100 gallons of solar oil, whilst of the remaining products 13 gallons are solvent spirit and 13 gallons an excellent varnish.

The analysis of both petrol and the gas obtained in this process shows that the changes which give rise to their formation are of the character first indicated by Thorpe and Young, and that heavy saturated molecules are splitting up into simpler saturated and unsaturated hydrocarbons; whilst it is of special interest to note that the unsaturated

hydrocarbons are chiefly napthenes, which suggests that the variations found in the character of crude oils are more likely due to different conditions of formation rather than to differences in origin.

It is clear that processes which rely for their commercial success ˆupon· the use of heavier fractions from the crude oil can successfully compete in the petrol market only whilst the raw material is sufficiently cheap to enable the manufacturing processes to be carried on at a profit, and the rise in price of the crude oil in the fields and the general rise in price of all petroleum products suggest that a gradual rise all round will continue, but this by no means follows, as the rise in the price of crude oil in the fields is due largely to the demand for oil to distil for petrol, whilst the rise in price of the other residuals in this country is due largely to shortage in shipping facilities and high freights, so that only the most paying product —*i.e.* petrol—has been chosen for shipment, and large stores of heavier fractions are being held back until the fleets of oil ships now under construction are completed, when with fall in freights a probable drop in price of heavier oil may be expected. Any source

of motor spirit, however, that is dependent on the supply of crude oil can last only for a limited period, and one's attention, therefore, turns naturally to coal as a source from which, volatile liquid hydrocarbons may be obtainable to eke out the supply.

When a good bituminous coal is subjected to destructive distillation the products formed vary with the temperature and conditions employed, which govern the secondary reactions taking place in the products of the primary decomposition, so that from a ton of such coal one can obtain 13,000 cubic feet of 14 candle-power gas and 9 gallons of poor tar, whilst under other conditions one can get 3500 cubic feet of rich gas and 30 gallons of tar, in each case the physical and chemical characteristics of the coke residue also showing a considerable difference.

These represent the two extremes possible, and it is found that as the tar increases in volume owing to the conditions of distillation, so its specific gravity falls, and it becomes more oily or 'paraffinoid' in character, whilst aromatic hydrocarbons are replaced by paraffins and naphthenes. In the ordinary methods of coal-gas manufacture, where gas yield is taken as the criterion of success, the

secondary changes and decompositions have
gone so far that the tar contains only a trace
of the more volatile portions, and the benzol
vapour is left in the gas as far as possible to
keep up its heating and lighting power.

The result of this is that the fraction of
tar consisting of benzol, toluol, and small
quantities of xylol is very low; and as only
a few of the large works treat the tar
themselves, and the largest proportion is used
for road-making, the total quantity available
from this source is only some 50,000 gallons per
annum of a quality that could be used as a
motor spirit, although some 15,000,000 tons of
coal are used annually in the production of gas.

The coke oven recovery plant presents
a much more promising source of benzol, as
not only is the initial yield larger owing to
the slow heating of a large mass of coal, but
the benzol vapour is scrubbed out of the gas.
In England only some 42 per cent. of the
17,000,000 tons of coal converted annually
into metallurgical coke is treated in recovery
plant, only 81 out of a total of 224 coking
works using such plant, and the total quantity
of benzol recovered is about 8,000,000 gallons,
probably over a third of this being exported.

At the present time the demand for a

smokeless fuel of more easy ignition than coke
and capable of burning with a flame, as well
as the demand for motor spirit, have given
rise to several processes in which further
modifications in carbonisation are being
attempted, and which yield much larger
volumes of liquid products, the lighter frac-
tions of which are more akin to petrol than to
benzol, and when these assume manufacturing
proportions they will help undoubtedly to
supply the ever-increasing demand.

Commercial benzol contains about 140
grains of sulphur per gallon, and has to
undergo a process of purification from this
before it is fitted for motor use, as otherwise
it gives a more than usually foul-smelling
exhaust, but in running it is 12 per cent.
more powerful than petrol, and as regards
elasticity and starting is quite as good.

The Scotch shale oil industry, concentrated
as it is upon the narrow strip of strata only
some six miles in width that stretches away
from near Dalmeny on the Firth of Forth to
the moorlands around Tarbrax and Cobbin-
shaw, also can subscribe its iota to the supply
of motor spirit, and under the normal con-
ditions of working yields about 600,000 gallons
of spirit per annum; but large as this quantity

sounds, it is only 0·75 per cent. of the
80,000,000 gallons consumed last year. It
must be remembered, however, that the new
Naval base at Rosyth is close to the shale-
fields, and every effort will probably be made
to increase the amount of fuel oil available
for the Navy, and as any increase in this
means also increase in the lighter fractions,
it is quite possible a larger quantity of motor
spirit will be available.

The world's stores of petroleum, coal, and
shale are all being rapidly depleted, and in
the not very distant future it will be to
alcohol that we shall have to turn, and it
will then be found that alcohol, denatured
with 10 per cent. of benzol and tinged by
a trace of aniline dye, will give a motor spirit
at once safer, more pleasant in use, and
sweeter in exhaust than the petrol of to-day;
and that although the calorific value of such
a mixture is only 0·6 of the value of petrol,
the smaller amount of air needed for its
combustion, the increased explosive range
of the mixture, and the higher compression
that could be used in the cylinder, all combine
to make it the ideal motor spirit, and one
about which no doubts can be raised as to the
possibility of future supply.

APPENDIXES

WEIGHTS AND MEASURES

AVOIRDUPOIS WEIGHT

Drachms.	Oz.	Lb.	Qr.	Cwt.	Ton.	French Grammes.
1 =	·0625 =	·0039 =	·000139 =	·000035 =	·0000174 =	1·771846
16 =	1 =	·0625 =	·00223 =	·000558 =	·000028 =	28·33954
256 =	16 =	1 =	·0357 =	·00893 =	·000447 =	453·50
7,168 =	448 =	28 =	1 =	·25 =	·0125 =	12,700
28,672 =	1,792 =	112 =	4 =	1 =	·05 =	50,802
573,440 =	35,840 =	2,240 =	80 =	20 =	1 =	1,016,048

LONG MEASURE

In.	Feet.	Yards.	Fath.	Poles.	Furl.	Mile.	French Metres.
1 =	·083 =	·02778 =	·0139 =	·005 =	·000126 =	·0000158 =	·0254
12 =	1 =	·333 =	·1667 =	·0606 =	·00151 =	·0001894 =	·3048
36 =	3 =	1 =	·5 =	·182 =	·00454 =	·000568 =	·9144
72 =	6 =	2 =	1 =	·361 =	·0091 =	·00136 =	1·8287
198 =	16½ =	5½ =	2¾ =	1 =	·025 =	·003125 =	5·0291
7,920 =	660 =	220 =	110 =	40 =	1 =	·125 =	201·16
63,360 =	5,280 =	1,760 =	880 =	320 =	8 =	1 =	1,609·315

MEASURE OF CAPACITY

Pints.		Gal.		Cub. Ft.		Litres.
1	=	·125	=	·02	=	·5676
8	=	1	=	·1004	=	4·541
16	=	2	=	·3208	=	9·082
64	=	8	=	1·283	=	36·32816
512	=	64	=	10·264	=	290·625
2,560	=	320	=	51·319	=	1,453·126
5,120	=	640	=	102·64	=	2,906·25

FOREIGN VALUES

					s.	D.
Austria-Hungary	.	1 Kronen (kr.)	.	.	0	10
Belgium, France, and						
Rumania	.	1 Franc	.	.	0	9⅝
Germany	.	1 Mark (M.)	.	.	1	0
Holland	.	1 Gulden (Fl.)	.	.	1	8
India	.	1 Rupee (R.)	.	.	1	4
		(nominal value, 2s.).				
Do.	.	1 Anna	.	.	0	1½
Italy	.	1 Lira	.	.	0	9⅗
Japan	.	1 Yen	.	.	2	0⅓
Russia	.	1 Rouble (Rbl.)	.	.	2·1	
Do.	.	1 Copec	.	.	0	0¼
United States	.	1 Dollar ($)	.	.	4	2
Do.	.	1 Cent.	.	.	0	0¼

FOREIGN MEASURES

1 Kilogramme (Kilo.)	.	2·204 Lb.
1 Hectolitre	.	22 Imperial Gallons.
1 Pood	.	36 Lb.
1 Ton (2240 (Lb.)	.	62·22 Poods.
United States Gallon	.	0·883 Imperial Gallons.
6 United States Gallons	.	5 Imperial Gallons.
1 Metric-ton (1000 Kilos)	.	2204 Lb.
1 Metre	.	3 Feet 3¼ Inches.
1 Kilometre	.	0·621 Mile.
1 Verst	.	0·663 Mile.
1 Dessatine	.	2·7 Acres.
1 Sagene	.	7 Feet.

USEFUL DATA

1 Oz. (Avoir.)	.	.	437·5 Grains.
Do.	.	.	28·35 Grammes.
1 Lb. (Avoir.)	.	.	16 Oz.
Do.	.	.	7000 Grains.
Do.	.	.	453·59 Grammes.
1 Gramme	.	.	·002204 Lb.
Do.	.	.	·03527 Oz.
Do.	.	.	15·492348 Grains.
1 Fl. Oz.	.	.	28·396 Cc.
Do.	.	.	1·7329 Cub. In.
1 Pint .	.	.	567·919 Cc.
Do.	.	.	·56792 Litre.
Do.	.	.	·020057 Cub. Ft.
Do.	.	.	34·659 Cub. In.
Do.	.	.	20 Oz.
1 Gallon	.	.	·16046 Cub. Ft.
Do.	.	.	277·274 Cub. In.
Do.	.	.	4·537 Litres.
Do.	.	.	10 Lb. of distilled water.
1 Cc.	.	.	·0610270784 Cub. In.
Do.	.	.	·282 Fl. Drams.
Do.	.	.	·00176 Pint.
Do.	.	.	·0352 Fl. Oz.
1 Litre .	.	.	·035216 Cub. Ft.
Do.	.	.	·220096 Gallon.
Do.	.	.	61·027 Cub. In.
Do.	.	.	1·761 Pint.
1 Cub. In.	.	.	16·386 Cc.
Do.	.	.	·0164 Litre.
Do.	.	.	·577 Fl. Oz.
Do.	.	.	·02885 Pint.
1 Cub. Ft.	.	.	28315·3 Cc.
Do.	.	.	28·3153 Litres.
Do.	.	.	6·2321 Gallons.
Do.	.	.	997·1364 Fl. Oz.
Do.	.	.	49·8569 Pints.

To reduce Inches to Metres	.	Multiply by	·0254
Do. Centimetres to Inches		do.	·3937
Do. Kilograms to Pounds .		do.	2·2046
Do. Litres to Gallons	.	do.	·22
Do. Gallons to Litres	.	do.	4·548

COMPARISON OF CENTIGRADE AND FAHRENHEIT THERMOMETER SCALES

Centi-grade.	Fahren-heit.	Centi-grade.	Fahren-heit.	Centi-grade.	Fahren-heit.
-90°	-130°	40°	104°	170°	338°
85°	121°	45°	113°	175°	347°
80°	112°	50°	122°	180°	356°
75°	103°	55°	131°	185°	365°
70°	94°	60°	140°	190°	374°
65°	85°	65°	149°	195°	383°
60°	76°	70°	158°	200°	392°
55°	67°	75°	167°	205°	401°
50°	58°	80°	176°	210°	410°
45°	49°	85°	185°	215°	⁓419°
40°	40°	90°	194°	220°	428°
35°	31°	95°	203°	225°	437°
30°	22°	100°	212°	230°	446°
25°	13°	105°	221°	235°	455°
20°	− 4°	110°	230°	240°	464°
15°	+5°	115°	239°	245°	473°
10°	14°	120°	248°	250°	482°
⁓ 5°	23°	125°	257°	255°	491°
0°	32°	130°	266°	260°	500°
+5°	41°	135°	275°	265°	409°
10°	50°	140°	284°	270°	518°
15°	59°	145°	293°	275°	527°
20°	68°	150°	302°	280°	536°
25°	77°	155°	311°	285°	545°
30°	86°	160°	320°	290°	554°
35°	95°	165°	329°	295°	563°

To convert °F. to °C. $\dfrac{(\text{°F.} - 32) \times 5}{9} = \text{°C.}$

Do. $\dfrac{\text{°C.} \times 9}{5} + 32 = \text{°F.}$

TABLE OF THE CORRESPONDING HEIGHTS OF THE BAROMETER IN MILLIMETRES AND ENGLISH INCHES.

Millimetres.	English inches.	Millimetres.	English inches.	Millimetres.	English inches.
720 =	28·347	739 =	29·095	758 =	29·843
721 =	28·386	740 =	29·134	759 =	29·882
722 =	28·425	741 =	29·174	760 =	29·922
723 =	28·465	742 =	29·213	761 =	29·961
724 =	28·504	743 =	29·252	762 =	30·000
725 =	28·543	744 =	29·292	763 =	30·039
726 =	28·583	745 =	29·331	764 =	30·079
727 =	28·622	746 =	29·370	765 =	30·118
728 =	28·662	747 =	29·410	766 =	30·158
729 =	28·701	748 =	29·449	767 =	30·197
730 =	28·740	749 =	29·488	768 =	30·236
731 =	28·780	750 =	29·528	769 =	30·276
732 =	28·819	751 =	29·567	770 =	30·315
733 =	28·858	752 =	29·606	771 =	30·355
734 =	28·898	753 =	29·645	772 =	30·394
735 =	28·937	754 =	29·685	773 =	30·433
736 =	28·976	755 =	29·724	774 =	30·473
737 =	29·016	756 =	29·764	775 =	30·512
738 =	29·055	757 =	29·803		

WEIGHT AND VOLUME OF GASES.

	WEIGHT.		VOLUME.	
	Per cubic metre in kilos.	Per cubic foot in pounds.	Per kilo. in cubic metres.	Per pound in cubic feet.
Air	1·29318	0·08073	0·773	12·385
Nitrogen	1·25616	0·07845	0·796	12·763
Oxygen	1·4298	0·08926	0·699	11·203
Hydrogen	0·08961	0·00559	11·160	178·83
Carbon dioxide	1·9666	0·12344	0·508	8·147
Carbon monoxide	1·2515	0·07817	0·800	12·800
Carbon vapour	1·0727	0·06696	0·932	14·930
Aqueous vapour	0·8047	0·05022	1·242	19·912
Sulphurous acid	2·8605	0·17877	0·349	5·596
Ethylene	1·2519	0·07814	0·799	12·797
Methane	0·7155	0·04466	1·397	22·391
Acetylene	1·1900	0·07428	0·840	13·456
Benzol	3·3333	0·208	0·303	4·808
Ethane	1·3415	0·08565	0·746	11·950

THERMAL UNITS

The British Thermal Unit is the amount of heat required
    to raise 1 lb. of pure water 1° F., or from 39·1° F.
    to 40·1° F.

The Large Calorie (French Unit) is the amount of heat
    required to raise 1 kilogram of water through 1° C.

The Small Calorie (Scientific Unit) is the amount of heat
    required to raise 1 gramme of water from 0° C.
    to 1° C.

The Pound Centigrade Unit is the amount of heat required
    to raise 1 lb. of water from 0° C. to 1° C.

British Thermal Unit. (B. Th. U.)	Large Calorie. (Ca.)	Small Calorie. (ca.)	Pound Centigrade Unit. (Lb. C. U.)	Foot-pounds.
1	0·252	252	0·555	778
3.9682	1	1000	2·2046	3080
0·003968	0·001	1	0·002046	3·08
1·8	0·4536	453·6	1	1397

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INDEX